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TESSAC EM-POWER TASK TECHNOLOGY CAPABILITIES SPECIFICATIONS.(U)

SEP 77 J FOUTZ, J L HENRY

UNCLASSIFIED NOSC/TD-110 NL

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Technical Document 110

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9 Final Rep[redacted]t.,

11 30 Sept[redacted] 1977
(Replaces Interim Report of 12 July 1977)

10 J. Foutz
J. W. Henry

12 164 p.

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RR GAVAZZI, CAPT USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

Work was done by the Power Electronics Branch of the Advanced Applications Division under OMN ELEX X (NOSC Q247). The document was approved for publication 30 September 1977.

Released by
CE Holland, Head
Advanced Applications
Division

Under authority of
CD Pierson, Jr, Head
Electronics Engineering and
Sciences Department

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NOSC Technical Document 110 (TD 110)	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) TESSAC EM-POWER TASK TECHNOLOGY CAPABILITIES SPECIFICATIONS	5. TYPE OF REPORT & PERIOD COVERED Final -- Replaces Interim report of 12 July 1977
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J Foutz and JL Henry	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center San Diego, California 92152	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS OMN ELEX X (NOSC Q247
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Electronic Systems Command (ELEX 095)	12. REPORT DATE 30 September 1977
	13. NUMBER OF PAGES 170
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic compatibility (EMC)
Electric power generation
Tactical Electromagnetic System Study (TESS)
Power supplies
Switching regulators
Power electronics
Power conversion
EMP

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

EM-Power is the TESSAC name for the subset of EMC, EMV, EMP, and EM-Safety related to the platform electrical power system, power conversion in electronic and other systems and signal ground. This document identifies EM-Power issues, discusses the state of EM-Power technology, identifies Navy capability in EM-Power, and discusses the adequacy of specifications and standards related to EM-Power.

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S/N 0102-LF-014-6601

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SUMMARY

INTRODUCTION

The Tactical Electromagnetic System Study (TESS) was a CNO sponsored eleven volume secret report documenting fleet electromagnetic system problems. The study was begun in 1969 and completed in 1973. A TESS Action Council (TESSAC) was established by NAVMAT in August 1975 to determine if the conclusions of the TESS report were still valid and to recommend a NAVMAT response. The TESSAC recommendations were completed in March 1976. As a result of these recommendations, the Chief of Naval Material requested TESSAC to investigate the state of the technology in Electromagnetic Effects (EME), the Navy laboratory and Systems Command technical capability in EME problem solving, and the adequacy of specifications and standards related to EME. In responding to the CNM request, six electromagnetic disciplines were identified and a technology task leader was assigned to each discipline. The disciplines, task leaders and their facility, and the resulting reports are listed in table S-1. These reports also contain additional information on the acquisition process and R&D needs related to each discipline. This information is to serve as inputs to reports recommending needed changes in the acquisition process and needed R&D.

TABLE S-1. TECHNOLOGY TASK REPORTS

TESSAC EM Discipline	Naval Facility and Technology Task Leader	Report
Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI)	Naval Post Graduate School, Monterey, CA Dr Richard Adler	ITTRI Tactical Electro-Magnetic Systems Action Council Electromagnetic Compatibility Survey of June 1977
Electromagnetic Vulnerability (EMV)	Naval Surface Weapons Center, Dahlgren, VA Mr Roger Schirmer	NSWC/DL TESSAC Final Report for EM Vulnerability of 2 June 1977
Electronic Counter Measures (ECM) and Electronic Counter Counter-Measures (ECCM)	Naval Research Laboratory, Washington, DC Mr Noel C Balthaser	NRL/TESSAC Secret Final Report on Electronic Countermeasures of 15 July 1977
Electromagnetic Pulse (EMP)	Naval Surface Weapons Center, White Oak, MD Dr Robert J Haislmaier	NSWC/IITRI TESSAC EMP Protection Engineering Study of 1 July 1977
Safety	Naval Ship Engineering Center, Washington, DC Mr John Roman	NAVSEC TESSAC Electromagnetic Safety Study Group Final Report of 31 August 1977 NOSC TD 110 Working Papers.
Electromagnetic Power (EM-Power)	Naval Ocean Systems Center San Diego, CA Mr Jerrold Foutz	TESSAC EM-Power Task Technology Capabilities Specifications (Interim Final Report of 12 July 77)

For the TESSAC discipline of EM-Power, this report identifies EM-Power issues, discusses the state of EM-Power technology, identifies Navy capability in EM-Power, and discusses the adequacy of specifications and standards related to EM-Power. EM-Power is the TESSAC name for the subset of EMC, EMV, EMP, and EM-Safety related to the platform electrical power system and the interface between the electrical power system and other electrical and electronic systems and equipment.

The investigation was made through a TESSAC EM-Power Technology Task Team of 10 members from Navy activities involved with generating and using electrical power on aircraft, ship, and shore platforms. A workshop with 13 participants from the same areas was also used. As required by the TESSAC Coordinator, on site visits were made to the Navy facilities with EM-Power capabilities.

PRIORITIES

To give focus to the study, priorities with respect to function, platform, and environment were established. The highest priority is any electromagnetic environment that can cause loss of power on Navy missions. These environments are most likely during combat conditions and include electromagnetic pulses. Electrical power is essential to all 15 mission areas of fleet units discussed in the Naval Combat Readiness Criteria. This fact and the impact on fleet equipment of even momentary power interruptions (table S-2) support the rationale for placing discontinuity of power first in establishing EM-Power electromagnetic effects priorities. These priorities are listed in table S-3.

TABLE S-2. RECOVERY TIME OF SHIPBOARD ELECTRONIC EQUIPMENT FROM MOMENTARY POWER INTERRUPTIONS (POWER RESTORED IN LESS THAN 3 TO 30 SECONDS)

Equipment Type	Time Range to Return to Operation (Minutes)	Time Range Full Equipment Performance (Minutes)
ECM	3	60
Radar PPI	3	30
Sonar (FC)	5	5
Sonar	1-30	5-30
Radar (Traffic Control)	3-15	60
Navigation Equipment	45-240 (3/4-4 h)	60-1200 (1-20 h)
Search Radar	3-10	5-60
Processing Equipment	1-180	180-300
Radio Communication Equipment	1-30	5-30

TABLE S-3. EM-POWER PRIORITIES

FUNCTIONAL PRIORITIES

CRITERION: Ability to perform mission

1. Discontinuity of power
2. Voltage and frequency variations
3. Load interactions
4. Voltage waveform distortion
5. Hull currents

PLATFORM PRIORITIES

CRITERIA: a) Presence of loads that degrade electric power
b) Presence of mission essential loads sensitive to degraded power

1. Ships/aircraft combining large surging or pulsing loads with sensitive digital processing systems or digital controls
2. Ships/aircraft with electronic control systems

ENVIRONMENTAL PRIORITIES

CRITERIA: a) Risk of discontinuity of power
b) Degradation of power system

1. EMP
2. Combat

ISSUES

Issues, as used in this report, are EM-Power topics that are pertinent to the Navy's ability to procure and operate systems that perform their missions in the various EM environments.

Thirteen issues in EM-Power are described in this report along with status. The implications for acquisition and R&D activities are also discussed.

The most important issues center around loss of mission capability when it is most needed – under combat conditions when stresses on the equipment from self-operation and external environments are highest. These survival issues included discontinuity of power (issue 2.1), EMP environments (issue 2.2), structure current coupling mode and susceptibility (issue 2.5), common mode noise rejection in interface circuits (issue 2.6), and shipboard signal grounding practices of doubtful merit (issue 2.7). Mission capability can be lost for hours by power interruptions of a few milliseconds. The EMP environment can result in a loss of power or can destroy or couple false information into interface circuits. Structure currents degrade performance margins if not minimized or if sensitive equipment is not desensitized. High EM environments often enter circuits as a common mode signal, the impact depending on the degree of common mode noise rejection. Present signal grounding practices on ships invite problems in the presence of high EM environments.

Other issues center around obtaining the initial operational capability. These include system stability (issue 2.4), pulse loads and harmonic currents (issue 2.3), and selection of input power (issue 2.8). The ship and aircraft generators are control loops that interface with other generators (as when they operate in parallel) and with complex loads that contain other control loops (ie, power supplies) that may have negative input resistance (ie, high-efficiency power supplies). The total system has to be and to remain stable. Pulse loads can mimic system instability, and pulse loads and harmonic currents can distort voltage waveforms to the extent that other equipment is affected. Selecting the wrong input power can add size and weight and increase failure rate with little or no compensating advantage. This category also has issues that are described in the loss-of-mission capability; ie, structure currents, common mode noise, and signal ground.

The final issues center around the effectiveness of getting the job done. These issues include contractual control (issue 2.9), analysis (issue 2.10), testing (issue 2.11), data and data bases (issue 2.12), and volatility of EM-Power capability (issue 2.13). Achieving contractor control (the Navy cost-effectively getting what it technically wants and needs) is unnecessarily complex as presently done. Navy EM-Power analysis capability generally lags the state of the art. Testing capability has been good but is rapidly being overtaken by more cost-effective approaches. Data and data bases are inadequate for the Navy user of data. The Navy capability in EM-Power is mostly in the background and experience of a few senior people. The capability is diverted by Naval Industrial Funding (NIF) funding practices and is highly volatile; much of it could be easily lost.

Each EM-Power issue has associated with it a goal – where we want to be; a status – where we are; and activities needed to move from where we are to where we want to be. This is illustrated in figure S-1. Where the activity is nonexistent or insufficient to achieve the goal, a deficiency exists. Table S-4 summarizes the EM-Power issues in terms of goal, status, and needed activities. An asterisk (*) is used to identify an activity as a deficiency. The unstarred activities are in-progress. Progress has to be monitored to assure they don't become a deficiency.

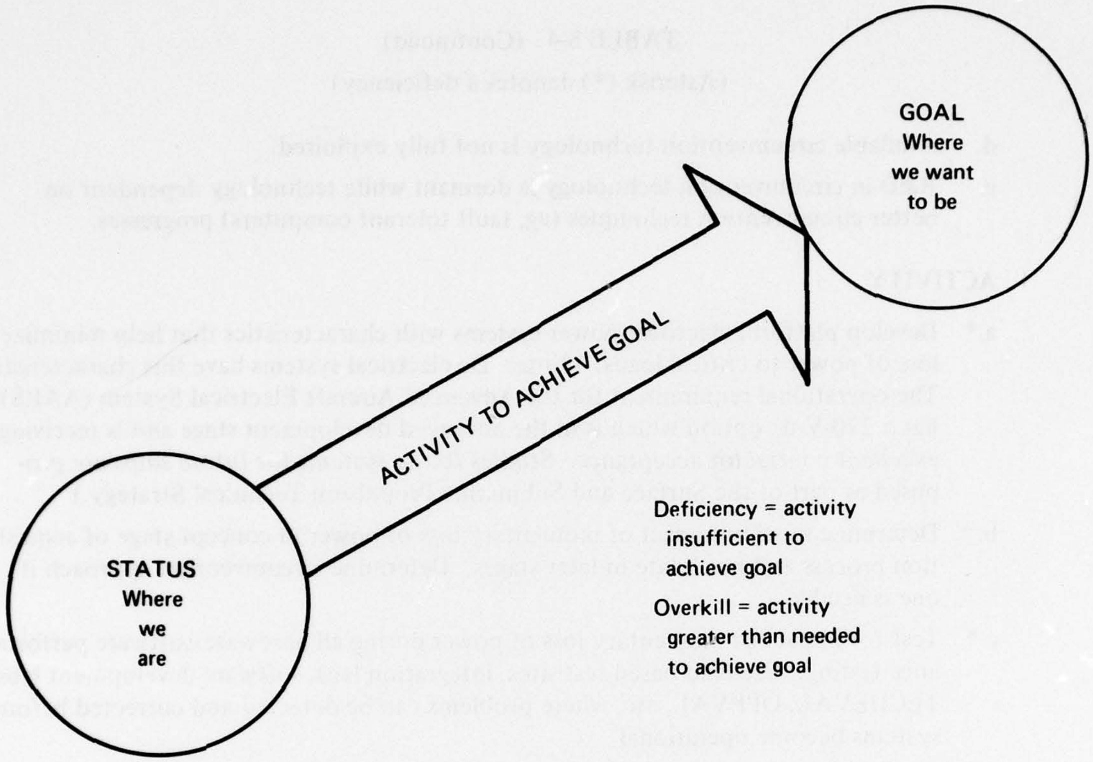

Figure S-1. Definitions: goals, status, activity, deficiency, and overkill

TABLE S-4. EM-POWER ISSUES
(Asterisk (*) denotes a deficiency)

1. DISCONTINUITY OF POWER

GOAL

a. Retention of mission capability during momentary loss of power.

b. Minimal occurrence of power interruptions, especially in high-stress EM environments (including EMP) likely to prevail in combat.

STATUS

a. Momentary power interruptions are characteristic of ac electrical system designs for ships and aircraft. Interruptions are most likely to occur in the high-stress EM-environment during combat.

b. Up to 20 hours is needed for some ship systems to recover from a momentary power interruption. Momentary power interruptions have kept aircraft from performing their mission.

c. Mission impact of momentary loss of power is often discovered very late in a program.

TABLE S-4. (Continued)

(Asterisk (*) denotes a deficiency)

d. Available circumvention technology is not fully exploited.

e. R&D in circumvention technology is dormant while technology dependent on better circumvention techniques (eg, fault tolerant computers) progresses.

ACTIVITY

a.* Develop platform electrical power systems with characteristics that help minimize loss of power to critical loads. (Note: Dc electrical systems have this characteristic. The operational requirement for the Advanced Aircraft Electrical System (AAES) has a 270-V dc option which is in the advanced development stage and is receiving excellent contractor acceptance. Studies for dc systems for future ships are proposed as part of the Surface and Submarine Propulsion Technical Strategy.)

b.* Determine mission impact of momentary loss of power in concept stage of acquisition process and revalidate in later stages. Determine circumvention approach if one is needed.

c.* Test for impact of momentary loss of power during all hardware/software performance testing. Use land based test sites, integration labs, software development labs, TECHEVAL, OPEVAL, etc. where problems can be detected and corrected before systems become operational.

d.* Develop catalog of available circumvention technology to support activity b.

e.* Initiate/maintain R&D in circumvention techniques at compatible level with R&D in related technology (eg, fault tolerant computers, graceful system degradation, EMP hardening), that may be dependent for effectiveness on circumventing a loss of power.

f.* Develop electrical performance and fault location systems (Maintenance Monitoring Systems) for ships to minimize power outages and minimize downtime and unnecessary maintenance.

g.* Develop automated electric plants for ships to maintain continuity (uninterruptible power) and required quality of electrical power.

2. ELECTROMAGNETIC PULSE (EMP)

GOAL

a. EMP hardened ship and aircraft electrical systems.

b. Electronic systems EMP hardened sufficiently so that they do not activate protective devices in the electrical power system.

c. Elimination of signal ground paths and common mode to differential mode conversions mechanisms that introduce the EMP into signal circuits.

d. Other goals as stated in the EMP report.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

STATUS

a. EMP hardness is an operational requirement (OR) of the Advanced Aircraft Electrical System (AAES). Because of this and the use of composite materials, electrical power returns will use wire or bus rather than the airframe. The impact of EMP on AAES solid-state controllers, signal transducers, the multiplex system, and the integrated system is yet to be determined.

b. Conventional/mandatory shipboard signal grounding practices appear to couple structure currents induced by EMP into ship electronic interface circuits. This is a potentially catastrophic situation.

c. Other status is in the EMP report.

ACTIVITY

a. Determine EMP effects on the Advanced Aircraft Electrical System (AAES) component and systems and perform EMP analysis and test.

b.* Determine the degree of EMP hardness needed by electronic systems used on AAES aircraft to prevent activation of AAES protective circuits.

c.* Investigate apparent coupling of EMP induced structure currents into shipboard electronics of present signal grounding practices. If problem, alert all project managers, determine solution options, and support program managers in solving problem for their system.

d. Other activities/deficiencies are in EMP report.

3. PULSE LOADS AND HARMONIC CURRENTS

GOAL

Reduced transients, modulation, and harmonic voltage distortion on the electrical systems of aircraft and ships and/or electronic equipment less sensitive to these influences.

STATUS

a. The inherent response of electrical systems to a single pulse load is a voltage transient and to repetitive pulse loads is a voltage modulation. The response to harmonic currents is harmonic voltage distortion of ac electrical power sources.

b. Many electronic systems are sensitive to modulation of the power source due to inadequate design margins or poor control-loop stabilizing techniques.

c. Past and most present general specification and qualification tests for electronic systems/equipment do not prevent or discover systems with modulation or pulse sensitivity deficiencies.

d. Switching regulators provide an excellent solution for design margin problems and are being used for this and other reasons. They are inherently insensitive to harmonic voltage distortion but are a major contributor to harmonic current. Switching

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

regulators can be stabilized to be insensitive to source transients and modulations, but most Navy contractors are unaware of the techniques and are not using them.

e. Filters, both passive and active, that are part of the electrical system on ships are under development at a low level of effort.

f. All-electronic filters and adaptive control techniques that are part of the electronic system are conceptually feasible but require extensive R&D.

g. Computer programs that can be used to predict the degree of the problem and the effectiveness of proposed solutions are just starting to be used. Additional programs and their wider use by Navy integration labs and contractors are needed.

ACTIVITY

a.* Reduce sensitivity of electronic systems to transient and modulation voltages by improving specifications, adequately testing for sensitivity, and making contractors aware of how better to design their control loops.

b.* Develop all-electronic and explore adaptive control methods to reduce pulse loads and harmonic currents drawn by electronics.

c.* Accelerate R&D for passive and active filters for adding to the electrical system of ships to correct for transients, modulation, and harmonic voltage distortions caused by ship loads.

d.* Accelerate R&D and application of computer programs that can predict problems and evaluate effectiveness of systems prior to building hardware.

4. SYSTEM STABILITY

GOAL

a. Navy systems that exploit all the advantages of feedback control systems without marginal stability or degradation of performance due to poor stabilizing techniques.

STATUS

a. The Navy has experienced many problems when subsystems, with control loops, have been integrated into a system. The problems are often resolved in a manner that degrades the performance of the subsystem or the integrated system.

b. High-efficiency power conversion equipments such as switching regulators have a negative input resistance since they only take from the source the power needed by the load. This type load is increasing at a rapid rate. Electrical power systems or their components are not tested for this type load.

c. Placing EMI filters between a negative input resistance load and the electrical source can cause the whole integrated system to go unstable. The conditions and cure for this have been worked out in the last two years and published in MIL-HDBK-241A. The problem and availability of a solution needs a wider awareness in the system engineering and EMC technical community. The techniques need to be adapted for computer simulation and data needed for simulation made part of contractual data requirements.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

d. Stability problems between the electrical power system and other systems are mostly solved by a cut and try approach with inadequate analysis or testing of the results. There are no good alternative methods to the cut and try method at present although extension of the techniques that solved the EMI filter problem is promising (an order of magnitude more complex problem). Testing techniques are available but not being applied.

e. Cost-effective computer simulation programs are needed to predict stability problems and verify the effectiveness of proposed solutions.

ACTIVITY

a.* Develop specifications and tests for electrical power systems and components that must operate with negative input resistance loads. This may require mutual constraints on the electrical and electronic systems.

b.* Develop analytical techniques for solving control system interaction problems and test techniques to verify the solution did not degrade the subsystem or system performance or reliability.

c.* Develop and apply computer programs to predict stability problems and verify effectiveness of solutions before hardware is built.

5. STRUCTURE CURRENTS (Ship Problem)

GOAL

a. Reduction of structure currents to acceptable levels and/or reducing sensitivity of electronic and other systems to structure current.

STATUS

a. The ship electrical system is floating (ungrounded to hull) so that the system still functions if a phase is shorted to hull. However, there is capacitive coupling to hull from parasitics and from line-to-chassis capacitors in equipment EMI filters. High-frequency components of power system harmonic voltage distortion are coupled into the hull by these means and create structure currents.

b. EMP, lightning, and a short of a power line phase to hull are also sources of transient hull current.

c. Some ship systems are affected by structure currents such as VLF communications, the degaussing system, and the ground fault detection circuits.

d. Electronic equipment is not specified or tested for sensitivity to chassis (one of the paths for structure currents) currents. MIL-STD-461 is being modified to include such tests.

e. The signal grounding practice for ships can bring structure currents into the signal ground system of ship electronic systems.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

ACTIVITY

a.* Reduce harmonic currents and therefore harmonic voltages that are the source for structure currents in the unstressed EM environment.

b.* Limit capacitance to chassis in EMI filters in electronic and other systems.

c.* Test suspected sensitive equipment for sensitivity to chassis current. Tailor detail specification until new MIL-STD-461 is released.

d.* Determine structure current coupling to electronic system signal ground caused by ship signal grounding practices. Determine impact on ship in a stressed EM-environment. Determine solutions if impact is unacceptable.

6. COMMON MODE NOISE

GOAL

a. Electronic systems insensitive to unstressed and stressed electromagnetic environments.

STATUS

a. Electromagnetic energy impinging on signal cables includes common mode currents in signal lines and returns. In a poorly designed system, the common mode signal is converted to differential mode and acted upon as a valid signal.

b. Most standard interface circuits used by the Navy are not specified for common mode noise rejection. This requirement is seldom part of the detailed specification.

c. Electronic equipment and systems are seldom tested for common mode noise rejection.

d. MIL-STD-461 common mode noise tests are being developed.

ACTIVITY

a.* Determine required common mode rejection needed during concept stage and select electronic or electro-optic approach to interface circuits. Specify degree of common mode noise rejection needed and determine test method.

b.* Develop low-cost interface circuits for standard interfaces with adequate common mode noise rejection.

c.* Develop low-cost standard electro-optic interface circuits.

7. SIGNAL GROUNDING

GOAL

a. A technically sound and consistent signal grounding philosophy for aircraft and ships controlled by general specifications.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

STATUS

a. On aircraft, the electrical system is grounded. The custom is to keep the signal ground isolated in each enclosure with grounding details determined in system integration. This is no problem.

b. On ships, the electrical system is floating. The custom is to tie signal ground to the chassis in each enclosure. In one specification this is made mandatory. This "wires" the structure into the signal circuits and gives a path for structure currents or voltages to disturb electronic signals.

ACTIVITY

a.* Develop a technically sound and consistent signal grounding philosophy for aircraft and ships and reflect this philosophy in the general specifications.

8. SELECTION OF INPUT POWER

GOAL

a. Use platform power as generated.

STATUS

a. Ship electrical power is generated as 3 phase, 60-Hz, 440-V ac. However, available options are single-phase, 400-Hz, and 115-V ac. Using any option incurs system penalties. Use of single-phase ac increases structure currents. Use of 400-Hz ac adds the weight and cost of frequency changers (with modern technology, 60-Hz and 400-Hz 3-phase power supplies are the same size and weight, which are less than previous 400-Hz designs). Use of 115-V ac requires the use of stepdown transformers, which, if needed, are best placed in the equipment for EMC purposes.

b. Aircraft power is generated as 115/200-V, 3-phase, 400-Hz ac with exploration and advanced development underway for 270-V dc. Avionic power supplies can be designed to operate from both 270-V dc and 115/200-V ac, 3-phase, with no size or weight penalty. Such avionics can be used on present and future aircraft with no penalties. If designed for 115/200-V ac only, a dc to ac inverter has to be added to the aircraft with 270-V dc power systems.

c. A standard family of power supplies compatible with 115/200-V ac and 270-V dc aircraft power and 3-phase, 60-Hz, 440-V ac shipboard power is under R&D.

d. Superconducting dc propulsion systems and dc links in solid-state frequency changers now under development could be modified and expanded to provide primary dc power for electronic systems.

ACTIVITY

a.* Require all future ship electronics to operate from 3-phase, 60-Hz, 440-V ac power.

b.* Require all future aircraft avionics to operate from both 115/200-V ac and 270-V dc.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

c. Continue the development of a standard family of power supplies compatible with ship and aircraft electrical power as generated.

d.* Standardize input dc voltage level requirements for future shipboard electronic loads and develop the means to provide it.

9. CONTRACTUAL CONTROL

GOAL

a. Better technical descriptions and control of Navy needs in contractual documents, especially specifications and standards.

STATUS

a. The general specifications and standards as now written do not sufficiently control EM-Power topics. The Navy has no good assurance the product will perform as intended in the electromagnetic environments. This places the burden on the system specification developed as an output of the validation phase, and on the reviewers of the contractor-generated documents. Since writers and reviewers of these documents are rarely cognizant of the wide variety of EM-Power problems, the risk of error in judgment is high.

ACTIVITY

a.* Develop a specification description of what the Navy needs for its systems/equipments to operate from platform power sources in various electromagnetic environments. Include tradeoffs, options, and rationale for the approaches developed. Reflect this description in the conjoint general specifcations controlling EM-Power. Until reflected in general specifications, use information to tailor the general specifications in the system specification.

10. ANALYSIS

GOAL

a. Better utilization of state-of-the-art analytical methods for resolving Navy EM-Power problems and developing Navy systems.

STATUS

a. Electric power systems and electronic power conversion circuits are complex, nonlinear, often discrete time systems, with widely varying time constants. In the past these systems have been hard to analyze. Analysis techniques have made rapid advances in the last few years. With relatively few exceptions the Navy EM-Power community is not using the analytical techniques available. This is also true of Navy contractors.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

ACTIVITY

a. Bring new power analysis techniques into the Navy, demonstrate as effective in solving Navy problems, and have Navy/contractor personnel trained in their use.

11. TESTING

GOAL

a. Cost-effective EM-Power testing that uncovers EM-Power problems early in the acquisition phase.

STATUS

a. The Navy EM-Power community has substantial test capability and instrumentation. However, the lack of analysis capability has hampered the effectiveness of some testing, the test instruments are being obsoleted by modern automated data acquisition systems, and the test data are often difficult to retrieve. A start in improving the situation has been made in testing aircraft electrical systems. MIL-STD-704 requirements have been changed in the B version of the standard to make it possible to measure all electrical system parameters by automated measuring techniques. These techniques are now being developed.

b. The land based test sites, system integration labs, etc. could be used to discover EM-Power problems, such as the system/mission impact of momentary loss of power, before the system is installed on its platform. In general, this is not being done.

ACTIVITY

a. Continue developing aircraft automated test techniques.

b.* Develop similar techniques for ship electrical power and electronics testing.

c.* Bring better analysis techniques on line to support test planning and interpretation.

d.* Utilize land based test sites, system integration labs, etc, to discover EM-Power problems before installation of the system on the platform.

e.* Establish a shipboard electrical/electronic interface simulation facility to provide means to effectively study interface problems and develop solutions.

TABLE S-4. (Continued)
(Asterisk (*) denotes a deficiency)

12. DATA AND DATA BASES

GOAL

a. Better acquisition, storage, and data retrieval of EM-Power information.

STATUS

a. EM-Power data needed for rational engineering decisions related to systems integration, systems changes, engineering change proposals, evaluation of software changes, waivers and deviations, etc, are just not available. The data needed may have been collected at some time in the acquisition process but were not delivered to the government or cannot be located by those needing the data.

ACTIVITY

a.* Add EM-Power data to data banks normally available. If these data prove insufficient, develop a data acquisition, storage, and retrieval file for EM-Power data.

13. VOLATILITY OF EM-POWER CAPABILITY

GOAL

a. Maintain and improve Navy technological capability in EM-Power.

STATUS

a. The Navy has a competent capability in EM-Power but that capability is highly volatile and could easily be decimated. Loss of one to three personnel would cause seven of the ten Navy facilities to lose their significant EM-Power capability. Once lost, a state-of-the-art EM-Power capability is not easy to recapture. Three labs have tried, only one has succeeded so far. The Navy has yet to capture a graduate from a school providing state-of-the-art training in power electronics.

b. The EM-Power organizations responsible for platform electrical power have reasonably clear lines of sponsorship, policy guidance, direction, and funding support. The same is true of EM-Power organizations responsible for system integration. This is not true for systems/equipments. The individual project or acquisition manager makes his own EM-Power decisions. This multiple independence leaves no one responsible for general sponsorship, policy guidance, direction, and funding for

general EM-Power technology for systems and equipments. One result is that there is no state-of-the-art capability in any of the SYSCOMs in EM-Power as related to systems and equipments. The only capability in the Navy resides at two facilities whose management has supported the necessity for this technology. Another result is that the same mistakes are repeated over and over again by the Navy and Navy contractors because the corporate memory is not centralized. The results of this diffusiveness are strongly felt by the more centralized platform and integration organizations. In working with problems across the electrical interface, they have to work with scores of people with little knowledge of the current technology. Few interface problems are resolved unless they can be resolved completely on the electrical side of the interface or in a single system or equipment. This situation makes it difficult to establish, maintain, and effectively use the technological capability in EM-Power related to systems and equipments.

ACTIVITY

a.* The Navy risks losing its EM-Power technological capability unless management action is taken to capture on a periodic basis graduate engineers with state-of-the-art power electronics training.

b.* Adequate sponsorship and funding of EM-Power technology are needed to maintain a state-of-the-art capability in EM-Power. For systems and equipment, there are no coordinated sponsorship and funding channels in EM-Power. This is wasteful of resources and places additional burdens on the platform EM-Power technical community.

STATE OF EM-POWER TECHNOLOGY

There has been a rapid expansion of EM-Power technology in recent years. Aerospace and DoD needs have continued to drive the technology to some extent, but a major new thrust has occurred because of the new emphasis on power and energy needs arising from the world energy crisis. The availability of new components from other technologies, as well as improvements in power components, also has had a major impact. This has resulted in new challenges and new funding sources. At the same time, graduate training in the field has increased, the literature base has increased dramatically, and employment opportunities for those working in the field have increased. One result has been a breakthrough in modeling and analysis, which has opened up the possibility of new circuit approaches and new power system architectures, which in turn have stimulated the need for new components. These topics are discussed and then related to the various EM-Power issues. In general, the technology to solve most EM-Power problems is available but not necessarily in the Navy or at many Navy contractors.

CAPABILITIES

The Navy EM-Power technical capability is located in the 10 organizations shown in table S-5. Four of the seven CNM-commanded laboratories and centers have some technical capability as well as NRL and CEL. The remaining technical capability is in five support functions to the NAVAIR, NAVSEA, and NAVFAC SYSCOMs.

TABLE S-5. PRIMARY EM-POWER MISSION/CAPABILITY

	Research and Development	Test and Evaluation	System Integration (RDT&E)
NADC	Aircraft Power	Aircraft Power	Aircraft
DTNSRDC	Shipboard Power	Shipboard Power	Ships/Submarines
NOSC	Electronics	–	Multiplatform, EMX
NUSC	–	–	Submarines
NRL	Aircraft Power	–	–
CEL	Shore Power	Shore Power	–
NAVSEC	Shipboard Power	Shipboard Power	Ships/Submarines
NATC	–	Aircraft Power	–
NAFI	Electronics*	Electronics*	–
NWSC	Specifications	–	–
NSWC	EMP	EMP	–

*Includes pilot and limited production and depot maintenance.

As shown in figure S-2 the various organizations working in EM-Power are concerned primarily with the electrical side of the power interface, or they are concerned primarily as users of electrical power on the electronics side of the interface, or they are concerned with system integration of electronic/electrical loads with the electrical system and with other systems.

The platform/electronic integration emphasis of the 10 organizations is shown in figure S-3.

The missions/capabilities of the ten organizations are shown in table S-5 along with the NSWC/WO who have EMP capability.

The Navy capability in many areas is dependent on one or two key people. The EM-Power capability would be lost to the Navy facility if these key people were lost. (This is not unusual in EM-Power. It was found to be true also of the universities and most contractors.) Details of the existing Navy capability and needed capabilities are given in appendixes B and C.

The leading government agency in EM-Power is NASA.

The status of R&D activities in the various government agencies active in the field is discussed in the Inter Agency Advanced Power Group (IAPG), a group existing for the sole use and benefit of the government.

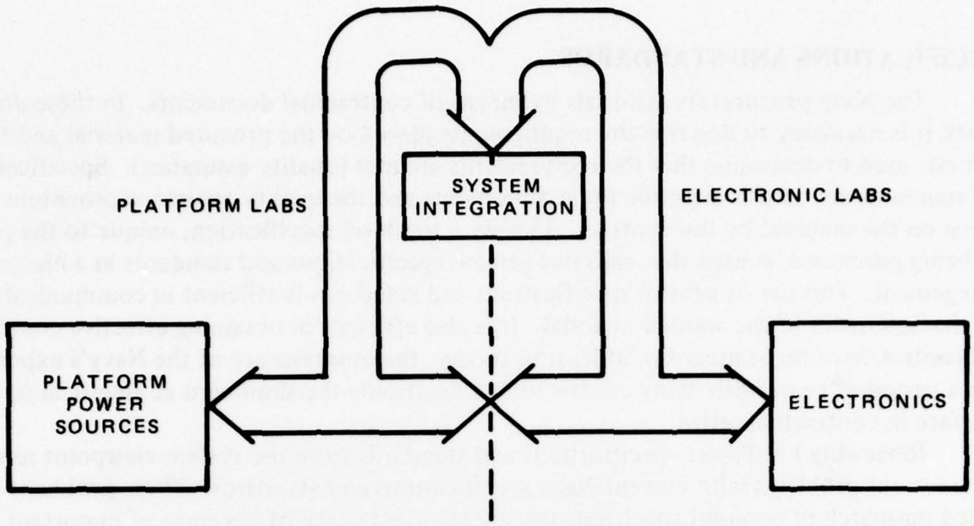

Figure S-2. Electrical power electronic interface.

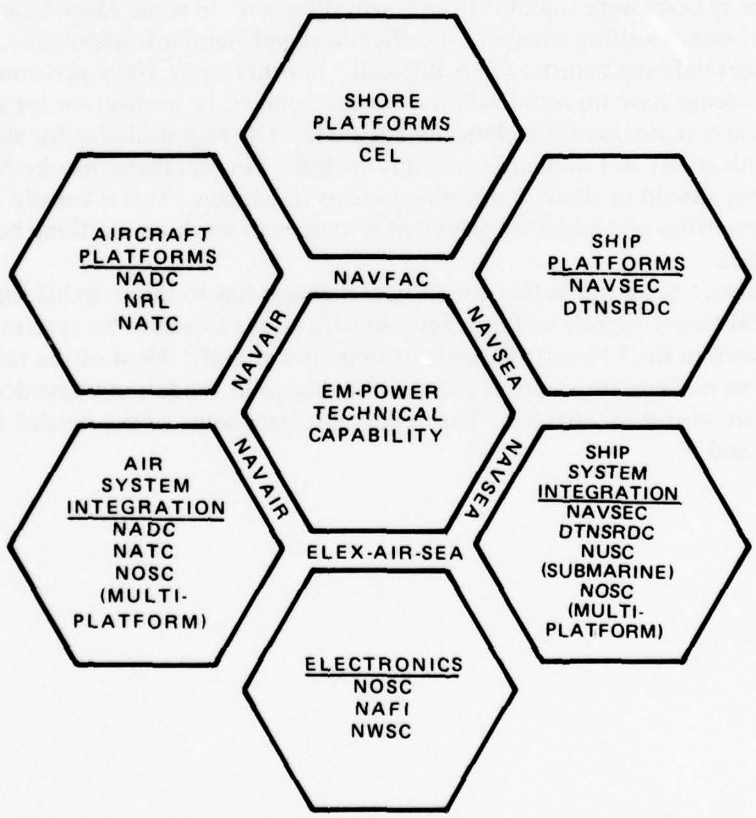

Figure S-3. EM-power capability, charters, and responsibility.

SPECIFICATIONS AND STANDARDS

The Navy procures its materials by means of contractual documents. In these documents, it is necessary to describe the requirements placed on the procured material and the methods used to determine that the requirements are met (quality assurance). Specifications and standards are used to describe the requirements and the quality assurance provisions placed on the material by the contract. Usually a top-level specification, unique to the product being purchased, is used that calls out general specifications and standards in a hierarchy arrangement. This use of general specifications and standards is efficient in communicating the characteristics of the wanted material. It is also efficient in obtaining effective contractual control since the standard is, at least in theory, the quintessence of the Navy's experience over a period of years with many contractors in describing the shipboard ac electrical power interface in contractual terms.

Reviewing EM-Power specifications and standards from the system viewpoint revealed many serious problems with current Navy specifications and standards. These problems included mismatch of conjoint specifications and standards, lack of coverage of important interface parameters, mismatch between the technology being used and the specification or standard, requirements in the specifications and standards forcing poor design practices, lack of technical guidance, lack of contractual control, and lack of adequate data requirements.

Several reasons were found for the above situation. In some cases, lack of good technical solutions makes writing adequate specifications and standards impossible. Lack of technical data makes defining realistic limits difficult. In other cases, Navy personnel with the technical knowledge have no responsibility, time, resources, or motivation for assuring that specifications and standards are technically adequate. The responsibility for assuring that conjoint specifications and standards match is unclear. Finally, there may be general agreement as to what should be done, but nothing seems to happen. This is usually caused by a hierarchy of priorities and a lack of sufficient resources to work on anything but the top one or two priorities.

The impact of all this is that the project manager has to tailor, in his top-level specifications, the EM-Power aspects of the general specifications to assure his system is properly specified to work in the EM environments of ships and aircraft. Most of the tailoring decisions need to be made in the concept phase for inclusion in validation phase documents. The relationships are shown in table S-6. This report discusses some of the needed tailoring in appendixes E and F.

TABLE S-6. PHASES AND CONCERNS IN DEVELOPING SPECIFICATIONS AND STANDARDS.

CONCERN \ PHASE	CONCEPTUAL	VALIDATION	DEVELOPMENT	PRODUCTION	DEPLOYMENT
1. Loss of power	1. Determine mission impact of loss of power. 2. If needed, develop loss-of-power circumvention approach.	Complete, expand, and validate requirements and approaches made in conceptual phase. Incorporate into system specification and determine test requirements for all significant requirements. Highest priority is mission impact of loss of power and circumvention details if loss of power is unacceptable.	Monitor development to assure that all EM-Power concerns are reflected in the development, detailed specifications, and test requirements, and that the tests and evaluations performed effectively demonstrate compliance with requirements and provide data needed for system integration. Land-based test sites, system integration labs, TECHEVAL, and OPEVAL should be used to the greatest extent possible to demonstrate mission/system impact of loss of power and effects of electrical simulation of EM environments (EMP, lightning, signal ground noise, noise, common mode noise, modulation of power system, etc), so that corrective actions can be made before production and deployment.	Monitor production to assure no degradation in EM-Power concerns because of cost-reduction activities, engineering changes, quality assurance provisions, etc. Be alert to anomalies that could indicate EM-Power problems. These anomalies can include loss of digital data in memory or data transfer, malfunctions caused by glitches in factory power, failure of power supplies, circuits, and interface components because of electrical overstress, loss of data, or failures in power turn on/off, etc.	Continual evaluation of impact of new threats, operations, etc, on ability to perform mission; ie, is loss of power more likely or more critical in terms of a new threat or operational approach? Does a new requirement to work in an EMP environment make common mode noise rejection more critical? Does a new ECCM tactic change the pulse loading on the power system? Is this acceptable? During EMCON, will loss of power turn on transmitters?
2. Power	1. Determine type of input power. 2. Estimate amount of power. 3. Determine approach for pulse loads.				
3. Electrical protection	Determine whether standard protection philosophy is satisfactory. If not, develop philosophy.				
4. EMI	1. Define EM environment. 2. Estimate contribution of equipment/system to environment.				
5. Grounding	1. Develop signal-grounding philosophy. 2. Determine isolation requirements.				
6. Signal interfaces	Determine types of interfaces and required performance in each EM environment.				
7. Corona	If high voltage system, determine impact of corona on life and EM environment. Determine approach.				
8. Data	Identify platform, type of power, amount of power, pulse loading, operation in EM environments, interface isolation, signal-grounding concept	1. System Specification. 2. Test Requirements.	1. System Description. 2. Test and Evaluation Results. 3. System integration data. 4. Corrective Actions	1. System integration data. 2. System and component failure data prior to and after acceptance testing.	1. Failure data. 2. Corrective Actions. 3. Lesson learned into acquisition cycle requirements, including specifications and standards.

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The findings and conclusions of this report in relationship to the stated goals are to be found in the Issues table, S-4, under the Status heading. The recommendations are under the Activity heading in the same table. The activities not marked by an asterisk are underway and should be continued if the goals are to be reached. Funding for this should be maintained, increased, or decreased on the basis of a) the priority of the goal, b) the priority of the approach, including synergism with other issues, and c) progress in relationship to interacting programs. The activities marked by an asterisk have not been initiated or have been only partially initiated. They are inputs into the normal Navy R&D and acquisition process. The issues in relationship to the statement of work requirements are indicated in table S-7.

In general, the technology to solve most EM-Power problems is available but not necessarily in the Navy or at many Navy contractors. The capability of Navy labs with respect to analysis is considerably behind the state-of-the-art. The ability to measure is good but is being overtaken by events. The specifications and standards are inadequate in several significant areas both by themselves and, especially, in relationship with other specifications.

Finally, this document is unique in the way it pulls together the status of EM-Power in the Navy. It has several weaknesses in both content and expression. These can be strengthened in later revisions. It is recommended this report be revised periodically to serve as a continuing basic reference.

TABLE S-7. ISSUES RELATED TO STATEMENT OF WORK

Issue	State of Technology	Capability to Calculate, Measure and Analyze and Correct EM-Power E^3	Specifications and Standards
1. Discontinuity of Power	X	X	X
2. Electromagnetic Pulse	X	X	
3. Pulse Loads and Harmonic Currents	X	X	X
4. System Stability	X	X	X
5. Structure Currents	X	X	X
6. Common Mode Noise	X	X	X
7. Signal Grounding	X	X	X
8. Selection of Input Power	X		X
9. Contractual Control			X
10. Analysis		X	
11. Testing		X	
12. Data and Data Bases		X	X
13. Volatility of EM-Power Capability		X	

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

1.1 AUTHORITY AND OBJECTIVE

On 12 April 1976, the Chief of Naval Material requested that the Tactical Electromagnetic System Study Action Council (TESSAC)

(a) Investigate the state of technology in Electromagnetic Environmental (EME) effects relative to Navy aircraft and ship platforms.

(b) Determine SYSCOM and Navy laboratory technical capabilities to calculate, measure, analyze, and correct equipment, system, and platform EME deficiencies.

(c) Examine the adequacy of current Navy specifications and standards in EME.

(d) Develop for the Naval Material Command detailed plans which ensure that the deleterious aspects of EME are adequately considered in the acquisition process.

(e) Develop a program for research and development to improve knowledge of the electromagnetic environment.[1-1]

In response to the CNM request, a technology task was formed, oriented toward the EME disciplines of electromagnetic compatibility and electromagnetic interference (EMC/EMI), electromagnetic vulnerability (EMV), electronic countermeasures and counter-countermeasures (ECM/ECCM), electromagnetic pulse (EMP), safety, and EM-Power. A technology team with a team leader was established for each EME discipline.[1-2]

Each technology team was given the statement of work[1-3] to respond in report format to (a), (b), and (c) above. In addition, information for (d) and (e) was to be provided.

This report meets the statement of work requirements for the EME technology discipline of EM-Power.

The ultimate objective of this work is to improve the capability of Fleet aircraft and surface ships in performing their missions in various self-induced and externally imposed electromagnetic environments through improved specifications and standards, improved acquisition procedures, and improved ability of the Navy to avoid and correct EME-related problems.

1.2 SCOPE/DEFINITIONS

EM-Power is the TESSAC name used for the subset of electromagnetic compatibility (EMC), electromagnetic vulnerability (EMV), electromagnetic pulse (EMP), and safety disciplines related to the platform electrical power system and the interface between the electrical power system and other electrical and electronic systems and equipments. Because the

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1-1. Naval Material Command ltr MAT 034/RBB, ELEX 095/RCW, subj TESS Action Council Report, 12 Apr 1975.

1-2. Naval Material Command ltr TESSAC/RCW 97-095, 24 Jun 1976, subj TESS Action Council, 24 Jun 1976.

1-3. Statement of Work for TESSAC Technical Teams, 28 Sep 1976.

signal ground of electronic systems is usually the power supply secondary ground in electronic equipment, the EM-Power discipline also includes signal grounding topics.

There are several reasons for separating EM-Power from the other EM disciplines in TESSAC. Electrical power is totally unique in that it is essential for all 15 mission areas of Fleet units as defined in the Naval Combat Readiness Criteria.[1-4] Degradation of electrical power by conducted and radiated electromagnetic interference is a widely recognized problem. However, by training and emphasis, most EMC engineers are poorly equipped to handle many of the special problems associated with EM-Power, most of which occur at frequencies below 150 kHz and may require a background in control theory. For this reason, specialists in power and power electronics are the repository for most of the specialized knowledge in this field. Separating EM-Power from the parent TESSAC disciplines recognizes this fact and facilitates identifying the specialized capability in EM-Power in the Navy.

If EM-Power were not a separate TESSAC discipline, it would be a subset of EMC with special topics in other disciplies (table 1-1).

TABLE 1-1. TESSAC/EM-POWER INTERRELATIONSHIP

EM-POWER	PARENT TESSAC DISCIPLINE
1. Radiated and conducted emissions on power lines related to power line frequencies, harmonics, and switching-mode power conversion frequencies. These are usually in the range of dc to 100 kHz.	EMC
2. Radiated and conducted susceptibility on power lines, and at frequencies below 100 kHz.	EMC and EMV
3. Signal grounding and common mode signal interference.	EMC
4. Electric shock hazard	EMC and Safety
5. EMP effects	EMP
6. Lightning	EMC, Safety, and EMV
7. System stability and stability-related interactions.	No TESSAC discipline. Usually a topic in control theory.
8. Continuity of power and protection of power source.	Usually a topic in electrical power system design and in reliability theory (redundancy). Some aspects might be in EMV.
9. Control and protective signal interactions.	EMC

1-4. OPNAVINST 3501.2D, OP-643C, 24 Jul 1974; from: Chief of Naval Operations, subj: Naval Combat Readiness Criteria.

The TESSAC EM-Power task specifically addressed only aircraft and surface ship platforms; however, if a capability developed for submarines, satellites, etc., was found to be applicable to aircraft or surface ships, it was to be included. For example, the EMC prediction methodology used in the TRIDENT program[1-5] was developed for use on a submarine system but could be used for a surface ship, aircraft, satellite, or missile.

TEMPEST topices and red/black separation, while important topics for those working with EM-Power, were excluded as being out of scope.

1.3 APPROACH

The EM-Power task was performed by an EM-Power Technology Task Team, an EM-Power workshop, and a two-man team that visited various facilities with EM-Power capability. Table 1-2 lists the EM-Power team members, the workshop participants, and the visiting team.

The EM-Power Technology Task Team consists of a cross section of the Navy's senior technical personnel in the EM-Power discipline. Its function was to provide leads to the information needed by the task, provide information, and review the final product for technical accuracy, credibility, and completeness.

The workshop also provided information, especially with respect to research and development needs, and served as a forum to discuss TESSAC EM-Power issues and resolve any potential conflicting viewpoints. The workshop was useful by itself, independent of TESSAC outputs. It was the first time in recent years that the Navy EM-Power community had met.

The function of the two-man visiting team was to add credibility to the task by observing capabilities in person and by talking to working engineers about TESSAC EM-Power problems. The visiting team members are also the authors of this report.

In addition to the team members and workshop attendees, the three persons listed in table 1-2 as other contributors made substantial contributions by supporting the task and sharing their knowledge of EM-Power topics or reviewing the report.

1.4 PRIORITIES

A report[1-6] preliminary to this report identified the platform/equipments/systems and electromagnetic environments of concern to EM-Power and ranked these concerns by priority. The priorities from that report, which is reproduced in its entirety as appendix A of this report, are summarized here.

1-5 NAVSHIPS 0900-078-1010 Rev C, TRIDENT Submarine Command and Control System EMC Control Plan, 10 Oct 1975.

1-6. TESSAC EM-Power Task, Platform/Equipment/System/Environment Priorities, Preliminary Report, Rev C, 22 Jan 1977, enclosure (2) to NELC ltr 3900, JF:bw, ser 4300-20, 22 Feb 1977.

TABLE 1-2. TESSAC/EM-POWER CONTRIBUTORS

TESSAC EM-POWER TECHNOLOGY TASK TEAM

J Foutz	NOSC, San Diego	Code 9234	AV 933-2752 (Leader)
PJ Johnson	NUSC, New London	Code 344	AV 636-2626
JH Jentz	NAFI, Indianapolis	Code 835	AV 724-3927
JD Segrest	NADC, Warminster	Code 6073	AV 441-2406
JO Koegel/ G Danks	NATC, Patuxent River	Code SY60	AV 356-4701
BJ Wilson	NRL, Wash DC	Code 5210.3	AV 297-3357
FL Henrickson	NAVSEA, Wash DC	Code 6156D	AV 222-6062
CR Young	DTNSRDC, Annapolis	Code 2781	AV 281-2467
R Van Winkle/ R Plew	NWSC, Crane	Code 30321	AV 482-1633
E Giorgi/ JL Brooks	CEL, Port Hueneme	Code L62	AV 360-5690

OTHER CONTRIBUTORS

WJ Prysner	NUSC, New London	Code 41	AV 636-2379
HR Boroson	DTNSRDC, Annapolis	Code 278	AV 281-2857
D McQueeney	NUSC, New London	Code 344	AV 636-3434

TESSAC EM-Power Workshop Participants
15, 16, 17 March 1977
Naval Research Laboratory, Wash DC

JD Segrest	NADC, Warminster	Code 6073	AV 441-2406
CR Young	DTNSRDC, Annapolis	Code 2781	AV 281-2467
V Pugliese	DTNSRDC, Annapolis	Code 2781	AV 281-2467
J Foutz	NOSC, San Diego	Code 9234	AV 933-2752 (Leader)
J. Henry	NOSC, San Diego	Code 9234	AV 933-2752 (Asst Leader)
PJ Johnson	NUSC, New London	Code 344	AV 636-2626
BJ Wilson	NRL, Wash DC	Code 5210.3	AV 297-3357 (Host)
JL Brooks	CEL, Port Hueneme	Code L62	AV 360-5690
JR Hoffler	NAVSEA, Wash DC	Code 6156D	AV 222-6062
G Danks	NATC, Patuxent River	Code SY60	AV 356-4701
JH Jentz	NAFI, Indianapolis	Code 835	AV 724-3927
R Plew	NWSC, Crane	Code 3026	AV 482-1633
LC Martin	Lawrence Livermore Laboratory		Observer

VISITING TEAM AND AUTHORS

J Foutz	NOSC, San Diego	Code 9234	AV 933-2752
J Henry	NOSC, San Diego	Code 9234	AV 933-2752

Electric power is totally unique in that it is essential for all 15 mission areas of Fleet units defined in the Naval Combat Readiness Criteria.[1-4]

The maximum impact upon mission areas in EM-Power occurs when continuity of power is lost. This is most likely to occur during combat operations where EME effects are the greatest, battle damage may occur, and there is a possibility of an electromagnetic pulse. The effect on mission capability resulting from even a momentary loss of power can be traumatic. Therefore, EME effects that can result in a loss of power have the highest priority.

EME situations that place the greatest dynamic load on the power system are the next priority. Again, this usually occurs during combat conditions and has the greatest effect on mission areas when the effects of the dynamic loading of the power system cause degradation of susceptible equipment. The major dynamic loads are large motors, electrical actuators, radars, sonars and pulsed high-power ECM, and high-energy weapons such as lasers.

The sensitivity of equipment and systems to power variations is also an important priority. There is no generic way to define sensitive equipment, but equipments employing digital data processing and automatic controls are of special interest because of their increasing use and their impact on mission capability when they malfunction.

1.5 INTRODUCTION SUMMARY

For the TESSAC discipline of EM-Power, this report identifies EM-Power issues, discusses the state of EM-Power technology, identifies Navy capability in EM-Power, and discusses the adequacy of specifications and standards related to EM-Power. EM-Power is the TESSAC name for the subset of EMC, EMV, EMP, and safety related to the platform electrical power system and the interface between the electrical power system and other electrical and electronic systems. It also includes signal ground topics.

The investigation was made through a TESSAC EM-Power Technology Task Team of 10 members from Navy activities involved with generating and using electrical power on aircraft, ship, and shore platforms. A workshop with 13 participants from the same areas was also used. Visits were made to Navy facilities with EM-Power capabilities.

To give focus to the study, priorities with respect to function, platform, and environment were established. The highest priority is any electromagnetic environment that can cause loss of power on Navy missions. These environments are most likely during combat conditions and include an electromagnetic pulse.

2.0 EM-POWER ISSUES

Issues, as used in this report, are EM-Power topics that a planner, manager, system designer, user, etc., should be aware of to minimize problems, risks, and costs and to maximize the probability that his system or equipment will perform its mission in the electromagnetic environment. Thirteen EM-Power issues are described, the status of each issue is given, and the implications for acquisition and R&D activities are discussed.

2.1 DISCONTINUITY OF POWER

<u>DESCRIPTION.</u> Electrical power is essential to all 15 mission areas of Fleet units (mission areas are listed in enclosure (3) of reference (1-4)). Thirteen of these mission areas involve either surface ships or aircraft or both. Without electrical power, these missions either cannot be performed at all or are severely hampered.

This is only part of the problem since restoration of electrical power does not necessarily immediately restore full mission capability. Reference 2-1 reports on the results of a survey of 37 Pacific Fleet ships asking for information about the frequency, criticality, and effect of momentary loss of power upon ship mission capabilities. Many equipments suffer performance degradation for extensive periods of time (up to 20 hours) before they recover full operational capability. Table 2-1 summarizes the recovery times for the 65 equipments investigated.

These equipments affect mission capabilities such as: loss of aircraft carrier ability to marshal aircraft, loss of precision landing control, aircraft identification, detection and tracking, fire-control coordination, missile firing, intercept control, ECM coordination, CIC data link, tactical displays, and navigational inputs to ship and aircraft. Loss of these mission capabilities has potentially serious effect on the ship safety and mission if the electrical power interruptions occur at a critical time. These interruptions occurred an average of 2.4 times per month for underway ships. Forty percent of the interruptions resulted in load equipment damage, degradation, or excessive downtime.

The problems with power interruptions on aircraft can be similar and equally severe. Even though the power interruption is usually shorter on aircraft, typically less than 50 milliseconds on switchover, the aircraft requirement for small size and lightweight equipments puts a practical limitation on the energy storage capability of each aircraft equipment power supply.

2-1. Chief of Naval Development, Navy Technology Projections, Part III, Advanced Systems Concepts, Improved Continuity of Shipboard Power, 1 Oct 1971.

TABLE 2-1. RECOVERY TIME OF SHIPBOARD ELECTRONIC EQUIPMENT FROM MOMENTARY POWER INTERRUPTIONS (POWER RESTORED IN LESS THAN 3 TO 30 SECONDS)

EQUIPMENT TYPE	TIME RANGE TO RETURN TO OPERATION (MINUTES)	TIME RANGE TO ACHIEVE FULL EQUIPMENT PERFORMANCE (MINUTES)
ECM	3	60
RADAR PPI	3	30
SONAR (FC)	5	5
SONAR	1-30	5-30
RADAR (TRAFFIC CONTROL)	3-15	60
NAVIGATION EQUIPMENT	45-240 (3/4-4 h)	60-1200 (1-20 h)
SEARCH RADAR	3-10	5-60
PROCESSING EQUIPMENT	1-180	180-300
RADIO COMMUNICATION EQUIPMENT	1-30	5-30

STATUS. It is unrealistic to assume continuous power on a Navy ship or aircraft, expecially during combat conditions when stress conditions are high* and the ship or aircraft suffers battle damage or risks exposure to an electromagnetic pulse. Power interruptions occur frequently in normal peacetime operations, and sometimes as an integral part of normal operations such as the switchover from ground power to aircraft power. Both ship and aircraft electrical power systems employ redundant power sources in the power system so that electrical power can be restored rapidly if it is interrupted.

For shipboard power, the redundant power source is either switched in by automatic bus transfer units or switched in manually. The limits for power interrupts on ships are specified as 0.5 to 20 seconds for all power except tightly regulated (Type III) 400-Hz power where it is specified as 0.5 to 3 seconds.[2-2] In practice, the load can be transferred in 50 ms but more often it is allowed to settle before the redundant source is connected. The

*During Vietnam operations, ship crews often found some solution to ease the problem. For example, one ship always de-energized the sonar prior to firing the ship's guns. Circuit breaker/relay bounce caused by the shock of firing the guns would set up electrical stress that catastrophically failed electronic components in the sonar if it were energized. Another ship hardwired around overly sensitive protective devices to maintain continuity of power during combat operations. While the original problems were reported, the ad hoc solutions that kept the ships running during combat were not reported. In some cases, the ship's officers were unaware of the fixes. This information was obtained in off-the-record discussions by the author with Navy enlisted men on ships returning from Vietnam operations concerning problems associated with electrical power.

2-2. Department of the Navy MIL-STD-1399, section 103, Interface Standard for Shipboard Systems, Electric Power, Alternating Currents, 1 Dec 1970.

actual power interruption is then about 3 to 12 seconds. Some weapon systems use manual transfer, since some equipment can be damaged if power is not sequenced on in a specified order. When the load equipment cannot tolerate an interruption of power, it usually contains internal batteries. For example, the AN/WSN-2 gyrocompass[2-3] contains a 28-V battery that will maintain continuous gyrocompass operation and up to 75 W of vital heading reference excitation for 30 minutes after loss of power.

In aircraft power systems, the redundant power source is transferred by a break-before-make contractor. The specification limit for power interruption is 50 ms maximum under normal operation. Interruptions under emergency conditions may be as long as 7 seconds.[2-4,5] When the load equipment cannot tolerate an interruption of power, the equipment usually contains some form of energy storage (capacitors or battery) or obtains power from two sources that are always energized and connected to the equipment. The high-voltage dc system (270 V dc)[2-6] is being designed to minimize power interruptions and make it simpler to provide power directly to a load from two energized redundant sources.

ACQUISITION CONSIDERATIONS. The mission impact of loss of power should be determined in the conceptual phase. If loss of power cannot be tolerated, a circumvention concept should be determined. These determinations can then be used to develop system/equipment specifications. The performance during loss of power should be determined at each stage in the acquisition cycle, especially at each integration stage. For example, the impact of a momentary loss of power (as short as 50 ms) in equipment using digital data processing under software control can be a strong function of the software being used. The recovery time can range from milliseconds to hours, depending on the software. As another example, some transmitters key on or change channels when power is interrupted.[2-7] This could be undesirable during operations requiring emission control. These problems can only be identified by testing the system response when power is interrupted. Testing for effects of interruption of power at various points in the acquisition processes, including system integration labs and software development labs, can resolve any problems before software/hardware is delivered to the Fleet. Even then it is important to test the effect of loss of power during simulated combat conditions.

R&D CONSIDERATIONS. Circumvention techniques for loss of power have not kept pace with other electronic developments. For example, fault-tolerant computing has made substantial improvements since the JPL-STAR computer[2-8] in every category except the

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2-3. Lipman, JS, The AN/WSN-2, A New Gyrocompass for a Modern US Navy, paper presented at the National Marine Meeting of the Institute of Navigators, San Diego, CA, 4-5 Nov 1976.

2-4. Department of Defense MIL-STD-704A, Electric Power, Aircraft Characteristics and Utilization of, 9 Aug 1966.

2-5. Department of Defense MIL-STD-704B, Aircraft Electric Power Characteristics, 17 November 1975.

2-6. OR-WSLO4, Operational Requirement (OR) Advanced Aircraft Electrical System (AAES), 8 Jul 1975.

2-7. NELC TN 2946, Susceptibility of Electronic Equipment to Power Source, Tests on AN/SRC-31, 16 July 1975.

2-8. Avizienis, A. et al, The STAR (Self-Testing and Repairing) Computer: An Investigation of the Theory and Practice of Fault-Tolerant Computer Design, IEEE Transactions on Computers, vol C-20, no 11, Nov 1971, 1312-1321.

way in which loss of power is treated. The hardware developed on the USAF Fault-Tolerant Computer Program still uses relay contacts for controlling power.[2-9]

2.2 ELECTROMAGNETIC PULSE (EMP)

DESCRIPTION. The response of an aircraft or ship to EMP is complex. As a first approximation, the EMP pulse can be considered an impulse function that excites a damped oscillatory current in the antennas and surface structure of the airframe or hull. The fundamental frequency's half wavelength is slightly longer than the largest dimension of the aircraft or ship. However, it contains many higher frequencies associated with resonances with the platform's smaller structures. The energy from this damped sinusoid is collected and channeled by power cables and signal lines into the electronic equipment enclosures. The power cables, which run the full length of the aircraft or hull, can be major collectors of the EMP energy and a major entry port into the electronics. Perhaps more important for ships, the EMP-generated surface currents can be "hardwired" into the signal system if customary ship signal grounding practices are used. This is an unacceptable situation. The coupling mechanism is discussed in the sections on structure currents (2.5) and signal ground (2.7).

STATUS. A separate TESSAC report on EMP (table 5-1) exists. The reader is referred to this report for status, acquisition considerations, and R&D recommendations. Special attention, in both R&D and acquisition, should be given to the signal ground and coupling mechanism on ships.

2.3 PULSE LOADS AND HARMONIC CURRENTS

DESCRIPTION. The generator systems on both aircraft and ships are second-order or higher-order control-loop systems. A step change in load current results in an overshoot or undershoot of the controlled generator voltage. The characteristic ringing frequency is between 0.8 and 25 Hz. If the pulse repetition rate of the load current excites the characteristic frequency of the generator control loop, a continual response that looks the same as a limit-cycle oscillation can occur. This is illustrated in figure 2-1, which is drawn from the response characteristics of the 400-Hz ship service generator on the PHM-1. Modulations at up to 80 V peak-to-peak have occurred in some systems as the result of a software change that altered the pulse repetition rate of the load.

Even if the pulse repetition rate does not excite the characteristic frequency of the generator control loop, the modulation frequency can interact with the harmonic currents caused by rectification, forming sidebands around the rectification harmonics and thereby increasing the harmonic voltage distortion of the power system.

A key point to remember is that a computer software change that alters the pulsing frequency can cause problems in systems that operated satisfactorily before the software change. The results can vary from additional glitches in the system resulting from reduction of design margins to failure of equipment on the power bus.

2-9. Presentation at the San Diego Computer Society of IEEE Meeting, 22 Mar 77, by Captain Larry W Kern, Senior Project Manager on Fault-Tolerant Computer Development Program.

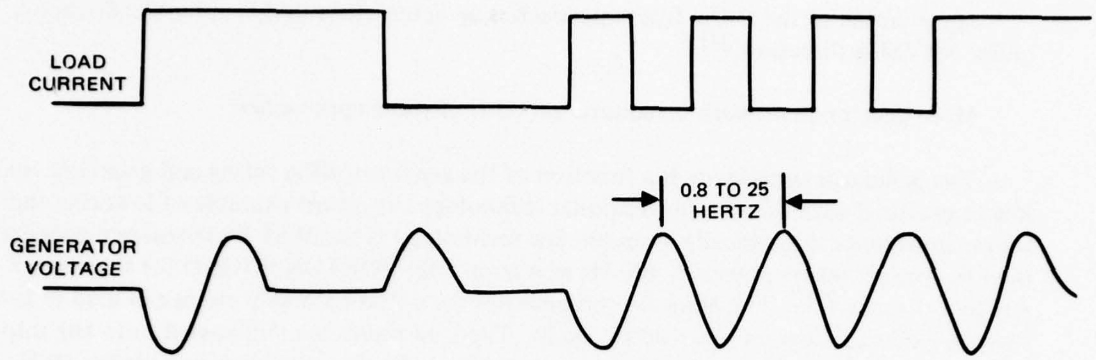

Figure 2-1. Generator response to load changes.

Harmonic currents are generated when a sinusoidal voltage is applied to a nonlinear load. Harmonic currents in electronic equipment are primarily caused by the rectification of ac power and the magnetizing current of iron-core transformers and motors. The magnetizing current has high harmonic content because of the nonlinear characteristics of iron-core magnetic circuits. Line unbalance can also generate harmonic currents.

The effect of harmonic currents in the system is a distortion of the voltage waveform of the power source through the source and system impedance and a decrease in power factor because of the presence of harmonic currents in the power system. The distorted voltage waveform, in turn, can cause problems in electronic equipment and can cause increased power losses in motors and other magnetic devices and reduce the torque of high-efficiency induction motors. The voltage distortion can also cause the excitation of undesirable vibration modes through magnetostrictive effects and other electrical/mechanical coupling mechanisms.

These effects are considered unacceptable in ship systems. For this reason, basic specifications such as MIL-E-16400 and MIL-F-18870 are being amended to limit harmonic currents to 3% or less of the fundamental. In addition, the test for conducted emission between 30 Hz and 20 kHz (CE01) of MIL-STD-461 is being required more often.

STATUS. Methods used to reduce the system impact of pulse loads (and harmonic currents) include the addition of active and passive filters to the system, lowering the source impedance of the generator, modifying the load to reduce or limit pulse loading, and modifying system time constants.

An example of the passive filter approach is a passive filter designed by DTNSRDC and tested on several ships.[2-10]

2-10. DTNSRDC report 76-0049, Investigation of Shipboard 400-Hz Power System Interface Problems, Dec 1976.

An example of the active filter approach is an active filter designed by Westinghouse under NAVSEA direction.[2-11]

More development work is required on both of these approaches.

The generator impedance is a function of the generator kVA rating and generally is as low as practical with present conventional technology. A recent example of lowering the source impedance dramatically through new technology is the Mark 84 frequency changer used to convert 60-Hz power to 400-Hz power on USS NORTON SOUND for the AEGIS AN/SPY-1 radar.[2-12] The Mark 84 compensates for a 270-kVA step change in load in less than 18 electrical degrees of a 400-Hz cycle. The load pulses are still passed onto the ship service 60-Hz system after some filtering by the Mark 84, but the lower impedance 60-Hz system is less affected by the pulses.

An example of modifying the load to reduce pulse loading is the AN/SPS-48 radar that added extra electric and inertia filtering elements between the cross field amplifiers and the power system to reduce, but not eliminate, pulse loading.[2-13]

All-electronic approaches for minimizing pulse loading by modifying the power supplies in the load show promise but require more development.[2-14]

Computer simulation techniques are being used in the development of the aircraft dc generators for the Advanced Aircraft Electrical Power System to make sure the generators operate compatibly with the pulsing caused by the dc-to-400-Hz inverter being developed on the same program.

One of the techniques used to minimize the impact of pulsing loads is to change system time constants. This can open up attenuation windows in the noise-rejection characteristics of the system, making the equipment more sensitive to power source characteristics. Shifting time constants is an excellent solution to the problem if done correctly with proper testing (no windows opened up). However, this is almost never the case and this approach, mis-applied, can be detrimental to the system.

Various approaches are being employed to reduce the harmonic currents, including the use of 12- and 24-pulse rectification, the use of harmonic trap filters, the use of larger low-pass filters, and the use of active techniques that add or subtract power to the line to cancel harmonic currents (active filters). These approaches, in general, increase the size, weight, and complexity of the electronic equipment power supply and can cause other problems such as instability of the power system or failure in one equipment inducing failures in other equipment. In the case of switching regulator power supplies, the size and weight of the power supply can double. Better technical approaches than those now being used are needed.

2-11. Spivak, M, 400-Hz Power Systems and Weapon Systems Electrical Interface Improvement, NAVSEA Journal, v 23, no 11, 34-35, Nov 1974.

2-12. NELC letter Code 4300 to CDR FE Beck, NAVSEA, subj: AEGIS Mark 84 Frequency Changer Technical Risk Assessment, 15 Nov 1975.

2-13. NELC TN 2828, Conversion of 400-Hz Shipboard Electronic Equipment to 60-Hz Electrical Power Sources, 7 Nov 1974.

2-14. IBM letter 20325/063 to J Foutz, NOSC Proposal for Power Supplies, 30 March 77.

ACQUISITION CONSIDERATIONS. Pulse loads should be identified in the conceptual stage of the acquisition process and methods of keeping the pulsing out of the power system considered. If this is not possible, simulation techniques should be used in the conceptual stage to determine whether the impact on the power source is satisfactory. Specifications should control the degree of allowed pulsing and harmonic currents. The system impact should be evaluated at each stage in the acquisition phase with problems resolved before installation aboard the platform. The effect of software changes on pulsing characteristics should be known, with evaluation at land sites prior to incorproation of software changes on the platform.

R&D CONSIDERATION. All of the present methods of solving pulsing load problems and harmonic currents are presently marginally satisfactory. They add size, weight, and complexity to the system and can introduce undesirable failure modes into the system. General methods of modifying system time constants without opening up attenuation windows are nonexistent in practice along with test methods to verify the results. How to better handle pulsing loads is a major R&D consideration.

2.4 SYSTEM STABILITY

DESCRIPTION. It is possible for the platform power source/load combination to go unstable in a control theory sense. Past examples include "load hopping" between paralleled generators in lightly loaded systems and instabilities from leading power factor loads in lightly loaded systems. The use of high-efficiency energy conversion techniques such as switching regulator power supplies is introducing a new type of system instability that can be expected to increase in the future if corrective action is not taken. High-efficiency power conversion techniques take from the power source only the power required by the load. This is illustrated in figure 2-2, which shows the input voltage versus input current for a constant power load. The derivation of the input resistance in the figure shows the input resistance to be negative, satisfying a requirement for a negative input impedance oscillator. It has been shown [2-15] that adding an EMI filter between the source and a negative input impedance load can cause the system to go unstable and, short of that, degrade important system parameters such as power supply output impedance and the ability of the power supply to prevent noise in the source from reaching the load. In a similar manner, loads using high-efficiency power conversion can interact with the power source control loops, causing stability problems.

STATUS: The type of negative input impedance oscillations described here has occurred in many systems including telephone switching stations, communication systems, satellite power supplies, and avionic systems. It appears as either rail-to-rail oscillations, limit cycle oscillation, or high oscillatory currents on the power source/load interface. The frequency can range from a few Hz to several hundred Hz. It is so little understood by the technical community that it is usually attributed to other causes and the solution approach is haphazard. The normal solutions used can substantially degrade the performance of the system, yet this degradation is neither analyzed nor tested.

2-15. RD Middlebrook, Input Filter Considerations in Design and Application of Switching Regulators, IEEE Industry Application Society Annual Metting, Chicago, IL, October 11-14, 1976.

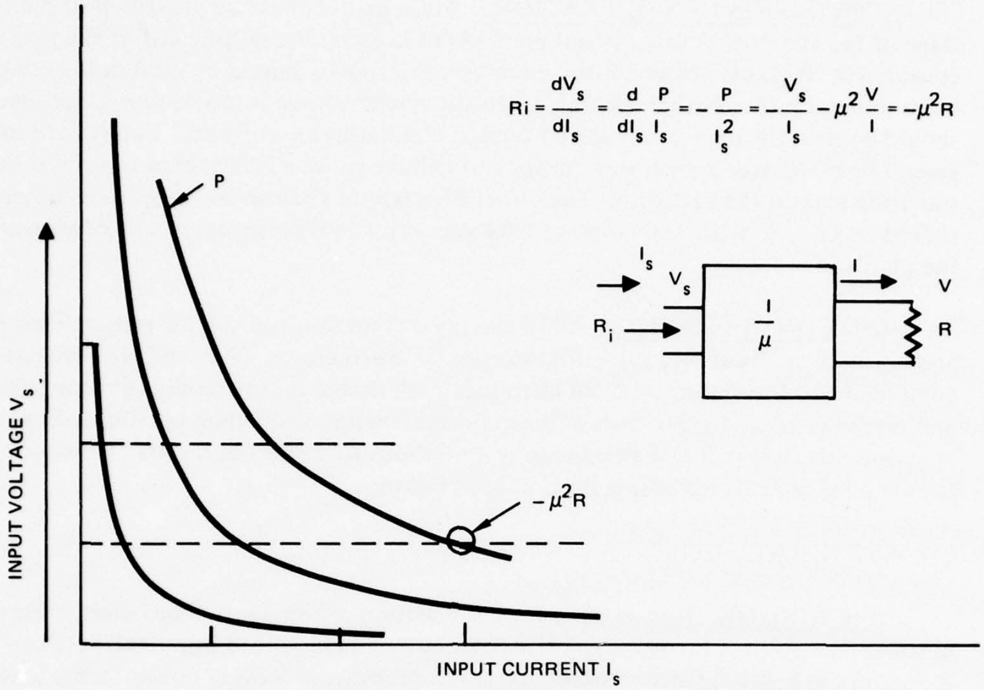

Figure 2-2. Switching regulator input characteristic.

A technical solution has been obtained for the case where an EMI filter is added to the system, and has been published in the technical literature[2-15] and in a Military Handbook.[2-16]

There is, as yet, no equivalent solution for the case where the oscillation is caused by the interaction of two control loops (ie, a ship service generator and a radar or sonar), although a start is being made.[2-17]

It is important to realize that negative input impedance is a characteristic of any high-efficiency method of power conversion, whether it be motor generator sets, static power converters, ferroresonant regulators, switching-mode power supplies, or switching-mode amplifiers. Since high-efficiency energy conversion has high system payoffs in reduced energy consumption and reduced cooling requirements, it is being used more and more. With this increasing use, more stability problems of this type can be expected.

ACQUISITION CONSIDERATIONS. Systems using high-efficiency power conversion have characteristics requiring new acquisition approaches. For example, analysis and solution of negative input impedance oscillations requires detailed knowledge of the EMI filter circuit.

2-16. MIL-HDPK-241A, Design Guide for EMI Reduction in Power Supplies.

2-17. Middlebrook, RD, and S Ćuk, Modeling and Analysis Methods for DC-to-DC Converters, IEEE International Semiconductor Power Converter Conference, Orlando, Florida, Mar 28-31, 1977.

These filters are usually procured by specifying their attenuation characteristics, which are meaningless in terms of solving the stability problem. Knowledge of the loop transfer characteristics is also required. Again, this information is seldom provided in the present acquisition process. In some cases, the normal design process is reversed. For instance, where heavy TEMPEST filtering is required, the design of the switching regulator power supply is heavily dependent on the TEMPEST filter. Trying to add the TEMPEST filter after the power supply is designed and concurrently meet TEMPEST and stability criteria may be impractical. The same may be true of trying to add EMP protection or additional EMI attenuation after the fact.

At present, generator control loops are designed and tested for resistive and/or inductive loads. As used, they may have to power both capacitive and negative impedance loads, a condition they are not usually specified for.

R&D CONSIDERATION. There is no good way of solving the instability problems that occur between the control loops in power systems and loads. The normal method, separating system time constraints, almost certainly degrades one system or the other. The degree of degradation is almost never analyzed or measured. The reason for this situation is unavailability of practical analytical and measurement tools. R&D is needed in this area.

2.5 STRUCTURE CURRENTS

The three-wire electrical power system on ships is of the floating type. There is no intentional grounding of any of the three power lines to the hull anywhere in the ship system. However, there is capacitance from each of the power lines to the hull. Although this stray capacitance to hull is significant, most of the capacitance is from line to chassis capacitors in equipment EMI filters. These capacitors establish a capacitive coupled ac ground at each equipment that varies in voltage from equipment to equipment. When the various equipments' chassis are bonded to the hull, these voltage differences are equalized by current flow in the low-impedance hull. The worst imbalance occurs when single-phase loads are used. These effects are shown in figure 2-3. The apices (ABC) of the triangle are the vector locations of the line voltages. The capacitive-coupled ground to hull is indicated by G. The different location of G at different points on the hull causes structure current to flow.

Electromagnetic fields, electromagnetic pulse effects, and lightning are other sources of structure current.

Some equipment is directly affected by current flowing in its structure; for example, the couplers used for very low frequency (VLF) communications.

Structure current can also be brought directly into active circuitry by "hardwire" connections. In Navy shipboard grounding practices, it is common to connect the signal ground to chassis in each equipment. In fact, MIL-F-18870E makes this mandatory for fire-control systems. It is also mandatory to tie the chassis to the hull. When nonisolated line drivers and receivers are used, also a common practice, structure currents can be brought directly into the interface circuits being used to communicate information between equipment. This mechanism is shown in figure 2-4.

On aircraft, the situation is different. The four-wire ac electrical system and two-wire dc electrical system are grounded to the airframe with signal ground usually floating until

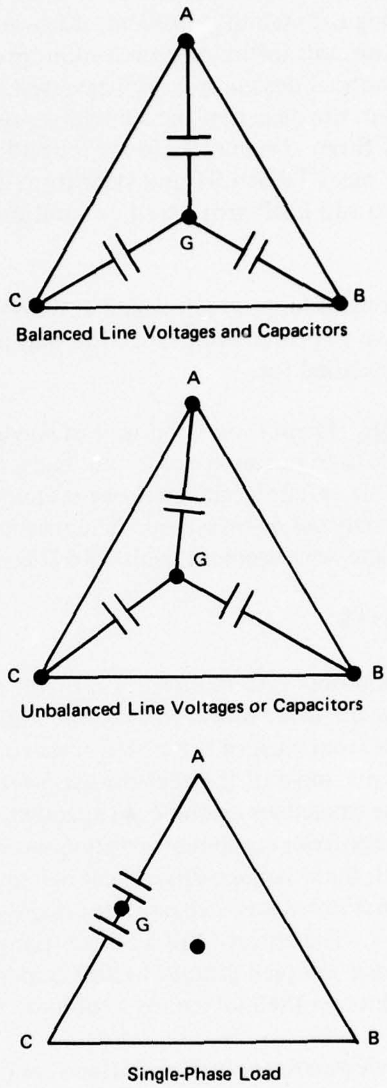

Figure 2-3. Capacitive-coupled grounds.

grounded during system integration. The result is that structure currents tend to interact with the power system instead of the signal system. The power system has been able to tolerate these structure current effects in the past. Aircraft power systems, which use solid-state devices extensively, may be more of a problem, requiring, as a minimum, the return of power currents by means of wire rather than the airframe.

STATUS. Structure currents from capacitance to ground can be minimized by stringently reducing capacitance to ground, avoiding single-phase loads, and adding isolation transformers between the source and equipment EMI filters. These techniques have little effect on external induced structure currents from electromagnetic fields, EMP, or lightning. The effects of structure currents can be minimized by using a pseudohull for signal grounding, such as the partially successful NTDS grounding approach, or, much better, by using isolated line drivers

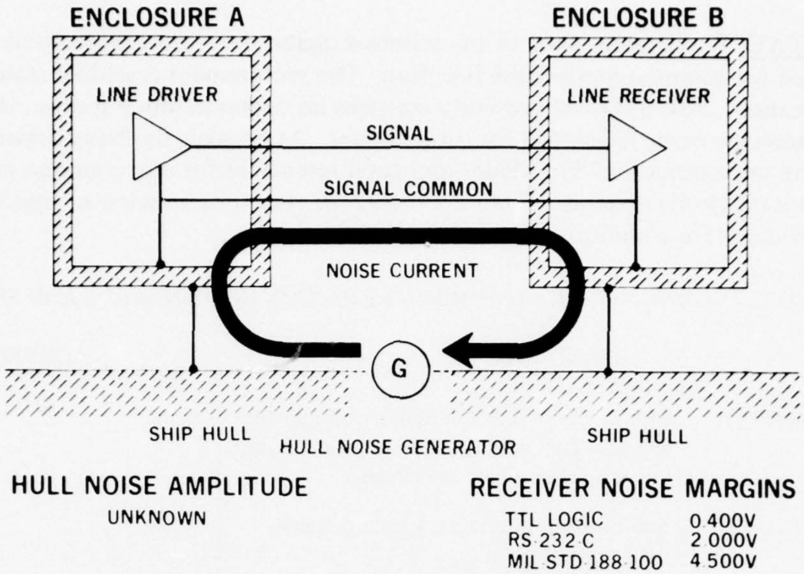

Figure 2-4. Signal common grounding: conducted interference.

or receivers with good common mode rejection (ie, the AEGIS ORTS system).[2-18] The latter is probably the only fully satisfactory solution for all electromagnetic environments, yet it is seldom used in Navy systems.

ACQUISITION CONSIDERATION. On both ship and aircraft equipment, capacitance from power line to chassis should be minimized by specification limit to values no greater than 0.5 μF, or better yet, 0.15 μF. Th use of single-phase loads on ships should be discouraged or prohibited. Fiber optic coupling of signals or isolated line drivers or receivers should be used.

R&D CONSIDERATIONS. Low-cost interface circuits with transformer or optical isolation, meeting standard interface requirements, and/or low-cost standard fiber optic signal interfaces need to be developed to make the most satisfactory approach more economically attractive.

2.6 COMMON MODE NOISE

DESCRIPTION. Electromagnetic energy impinging on signal cables induces common mode currents in signal lines and returns. The effect on the system depends on the magnitude of the induced signals and the common mode noise rejection of the signal driver, receiver, cable, and grounding configuration. In a poorly designed system, the common mode signal is converted to differential mode and acted upon as a valid differential signal. Recent examples include the pegging of indicator meters in shipboard engineering stations and the shutdown of power inverters when a ship HF transmitter was keyed.

2-18. Automation Industries Inc. VITRO Laboratories Division Technical Note 02025.04-1, Cable Installation Practices, Considerations for Cable Selection and Design of Installation for Shielded Cables to Achieve Maximum Performance and Electromagnetic Compatibility, Sept 1976.

STATUS. Virtually none of the standard digital interface circuits used in the Navy are specified for common mode noise rejection. The requirement is seldom stated in detailed specification. MIL-STD-461 presently contains no common mode testing, although common mode tests are being developed for future issues. At present, the Navy depends almost entirely on the contractors' knowledge and good intentions for any common mode noise rejection it gets in its systems. Table 2-2 shows the results of a review of interface specifications and standards for common mode noise rejection.

TABLE 2-2. COMMON MODE NOISE (CMN) REJECTION IN STANDARDS AND SPECIFICATIONS

STANDARDS		CONTROL OF CMN
RS-232-C(EIA)	Interface between data terminal equipment and data communication equipment employing serial binary data interchange	None
MIL-STD-1397 (SHIPS)	Input/output interfaces, standard digital data, Navy systems	None
MIL-STD-188 -100	Common long-haul and tactical communication	Immunity specified for balanced low-level digital interface – none for unbalanced low level – none for high level
SPECIFICATIONS		
MIL-M-28787 (NAVY)	Standard Electronic Module (SEM) program modules (Seven interface modules, five receivers, and two drivers were reviewed)	None for five interface modules – immunity specified for two interface receivers

ACQUISITION CONSIDERATIONS. Common mode noise rejection criterial should be determined in the concept phase and incorporated in the system specifications. Common mode noise rejection should be demonstrated by test on prototype and production hardware.

R&D CONSIDERATIONS. The common mode noise rejection capability of standard interface circuits should be determined and controlled by specification. When standard circuits are found to be inadequate, low-cost interface circuits with adequate common mode noise rejection should be developed. R&D may be required to determine what is adequate common mode noise rejection in the EM environment, including EMP effects.

2.7 SIGNAL GROUNDING

DESCRIPTION. There are several types of ground in systems: power ground, chassis ground, shield ground, and signal ground. The specifications are clear with respect to power ground. On aircraft, the power system is grounded to the airframe, which, on most aircraft, serves as a return for single-phase ac and dc loads (this may not be desirable in EMP environments or in composite material aircraft). On ships, the power system is ungrounded but will still operate if one phase is shorted to the hull because of battle damage or some other reason. The equipment enclosure on both aircraft and ships is bonded to the airframe or hull for safety reasons. Shields are single-point grounded or multipoint grounded, depending on the

frequency of the signal. With one exception, the specifications are silent with regard to signal grounding. On aircraft, the custom is to keep the signal ground isolated in each enclosure with a single ground point to the airframe being selected during system integration. This gives considerable flexibility in solving ground problems and appears to work reasonably well. This custom is not controlled by the general specifications. On ships, the custom is to ground each signal system to the enclosure of each equipment. MIL-F-18870E makes the approach mandatory for fire-control systems. As can be seen from figure 2-4, this gives a path for structure currents to flow into the electronic system, making the equipment highly susceptible to high EM fields, lightning, and EMP unless isolated line drivers or receivers are used to break up the current paths. There is no general requirement to break up these signal ground paths with isolation circuits.

STATUS. Current shipboard practice and specifications force a signal ground configuration on ships that invites damage and malfunctions in high EM environments. This is a critical problem that can degrade equipment operations under normal environments and can incapacitate equipment in high EM environments.

ACQUISITION CONSIDERATIONS. Grounding philosophy should be determined in the conceptual phase and be consistently controlled in the detailed specification. The project manager will have to determine the signal ground philosophy, since the general specifications are silent or force poor design practice. Some existing equipments may be incompatible with a rational grounding philosophy, and special thought will have to be given to these equipments.

R&D CONSIDERATIONS. A technically sound and consistent signal grounding philosophy for aircraft and ships needs to be developed and reflected in the general specifications.

2.8 SELECTION OF INPUT POWER

DESCRIPTION. While not directly related to EM-Power, the type of input power selected for electronics can greatly affect system weight. In general, power should be used as generated on the platform or system tradeoffs should be initiated to support any other approach.

For ships, this means 3-phase, 60-Hz, 440-V ac. Three-phase because using single-phase power increases structure currents as previously discussed; 60-Hz instead of 400-Hz because of the weight cost of making the 60- to 400-Hz frequency transformation. The weight savings shown in figure 2-5 is for older technology. Present technology uses switching regulators which are frequency independent and the use of 400-Hz in preference to 60-Hz ac results in no additional weight savings; however, the weight cost of the frequency changers remains.[2-19] Using 400-V ac instead of 115-V ac avoids the employment of a stepdown transformer which, if needed, is best used in the electronic systems to give better EMI control.

2-19. NOSC TD 107, Reduction of Shipboard 400-Hz Power Requirements, by E Kamm and J Foutz, 16 May 1977.

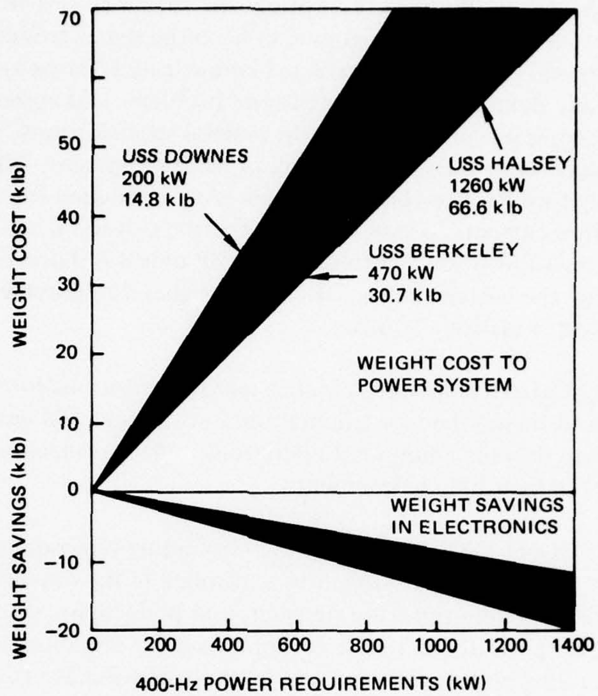

Figure 2-5. Shipboard weight cost versus weight saving using 400-Hz Power instead of 60-Hz power.

For aircraft, avionics should be designed to operate from 3-phase, 200-V ac or 270-V dc. In this way, the same equipment can operate from present aircraft ac voltage or the new Advanced Aircraft Electrical System.[1-12] Designing for 270-V dc only adds a small weight penalty (six rectifier diodes) to avionics for present aircraft. Designing for ac power, on the other hand, will add a large weight penalty (an inverter is required) to future aircraft. The important point is that, since 270-V dc is the voltage obtained from direct rectification of 115/200-V ac power, there is no weight or cost penalty for designing avionics for both.

STATUS. Ship specifications and deviation procedures are being modified to make it more difficult to obtain approval to use 400-Hz ac for electronics on ships.

The Advanced Aircraft Electrical System advance development design is progressing with heavy emphasis on generating primary electrical power at 270 V dc. Solid-state inverters will supply 400-Hz ac power to avionics loads that cannot be easily modified to 270 V dc.

ACQUISITION CONSIDERATIONS. Ship electronics should be designed for 3-phase, 60-Hz, 440-V ac power, and avionics for 270-V dc and 3-phase, 200-V ac power. If other input power is desired, tradeoffs should be performed in the concept phase.

R&D CONSIDERATION. A standard family of power supplies compatible with shipboard 3-phase, 60-Hz, 440-V ac and aircraft 270-V dc or 200-V ac is being developed for the Navy Standard Electronic Module (SEM) Program by means of ELEX 304 R&D funds. This family should be completed for shipboard and avionics applications. Some consideration is being given to dc systems for surface ships [2-20] and submarines.[2-21] The most promising voltage is 270-V dc (rectified 115/200-V ac) or 160-V dc (rectified 115-V ac). The former is compatible with aircraft primary power; the latter is compatible with 115-V ac ship power and commercial power. If dc systems appear promising, selecting one voltage for all platforms would ease the design of multiplatform electronics.

2.9 CONTRACTOR CONTROL

DESCRIPTION. The contractor is controlled by the terms and conditions of the contract. If the contract requires designs that do not meet the Navy's needs, the contract, not Navy needs, has precedence. The importance of the Navy's needs is not being accurately reflected in contractual documents. These documents are the contract, the system specification, the general specifications and standards invoked by the system specification, the data requirements, and the approval provisions for electromagnetic control plans, test plans, detailed specifications, etc, that become part of the contractual requirements when approved.

Effective contractor control is best achieved by general specifications and standards that are clear, complete, consistent with each other, accurately reflect the Navy's needs, have adequate quality assurance, and have built-in default values for any decisions referred to in the contract or system specification. The general specifications and standards have developed over the years with hundreds of people reading them, using them, asking for deviations and waivers, and objecting to provisions they are uncomfortable with. The mechanism for perfecting the general specifications and standards is available even though it is not always effective. The system specifications released as part of the validation phase have been developed in a much shorter period of time and are reviewed by a limited number of Navy personnel and eventually the contractors bidding on the contract. After the award of the contract, electromagnetic control plans, test plans, and detailed specifications are reviewed only by the originating contractor and a few Navy personnel usually working under time pressure. The result of this process is that the later in the acquisition contract that contractual control is achieved, the higher the probability of oversights, gaps, and mistakes that work to the detriment of the Navy.

STATUS. The general specifications and standards as now written do not sufficiently control EM-Power topics, so that the Navy has no good assurance that the product will perform as intended in expected electromagnetic environments. This places the burden on the system specification developed as an output of the validation phase, and on the reviewers of the contractor-generated documents. Since the writers and reviewers of these documents are rarely cognizant of the wide variety of EM-Power problems, the risk of errors in judgment is high.

2-20. Marcous, LF, Technical Strategy Surface and Submarine Propulsion, Executive Summary, DTNSRDC ltr rpt, 16 March 1977.

2-21. General Dynamics Electric Boat Division, Presentation to NOSC on SSBN Technology Program, May 25, 1977.

ACQUISITION CONSIDERATION. Contractual control of EM-Power topics is not fully achieved through present general specifications and standards. This places the burden of adequate control on the system specification generated in the validation phase. This condition will exist until the general specifications are updated to give sufficient control.

R&D CONSIDERATIONS. Research and development tasks are directed towards finding better ways for the Navy to resolve its problems and meet its missions. The findings of R&D, to be effective, have to be incorporated in a timely manner into the general specifications and standards. This is often not done. A dependable way to incorporate knowledge gained in R&D into the specifications and standards used to acquire Navy equipment needs to be found.

2.10 ANALYSIS

DESCRIPTION. Analysis is used to predict system performance before the system is built or used in a new application. Simulation, modeling, and analysis techniques are all available. The advantage of analysis is that problems can be resolved on paper before costly hardware, that may not perform as desired, is built. Analysis can also allow the determination of performance in difficult-to-create environments such as EMP. Power systems are complex, nonlinear, often discrete time systems, with widely varying time constants. In the past, these systems have been difficult to analyze. As a consequence, measurement has been relied upon to the extent that analysis is little used by the Navy EM-Power technical community.

STATUS. Analysis techniques in the EM-Power field have made rapid advances in the last few years. The best examples are the subprograms in the NASA Modeling and Analysis of Power Processing Systems (MAPPS).[2-22] The MAPPS programs determine stability and performance of power conversion equipment or systems and allow the optimization of weight or efficiency of an individual equipment or collection of equipments configured into a system. Other examples are the design-oriented circuit analysis approach developed at the California Institute of Technology[2-17] and the EMI prediction technology developed at the Moore School of Engineering under NUSC/NAVSEC direction,[2-23] and the state plane and other techniques developed at Duke University.[2-24]

The problem of digital simulation of systems with widely varying time constants that required analog or hybrid simulation of power systems has been largely resolved[2-25,26] and cost-effective digital simulation is now practical.

2-22. NASA Contract NAS-3-19690, Modeling and Analysis of Power Processing Systems (MAPPS), Presentation of NASA Lewis Research Center, 3 Feb 1977.

2-23. Moore School Report 74-03, Systems Electromagnetic Compatibility Evaluation, NAVSEA Contract N00024-72-C-1413, with University of Pennsylvania, 31 Aug 1973.

2-24. Huffman, SD, et al, Fast-Response Free-Running Frequency-Stabilized DC-to-DC Converter Employing a State-Plane-Trajectory Control Law, Presented at 8th Annaul Power Electronics Specialists Conference, Palo Alto, CA, 14–16 Jun 1977.

2-25. Blattner, DJ, Choosing the Right Programs for Computer-Aided Design, Electronics, 29 Apr 1976.

2-26. Owens, HA, et al, Simulation and Analysis Methods for Sampled Power Electronic Systems, IEEE Power Electronics Specialist Conference, Cleveland, Ohio, 8–10 Jun 1976.

With relatively few exceptions, the Navy EM-Power community is not using the state-of-the-art analytical techniques available. This is also true of most Navy contractors. If the problem cannot be solved with a handbook and slide-rule approach, a test-modify-retest approach is usually used by the Navy or its contractors. If an analytical approach is needed, the Navy usually contracts it out to a specialty house or the Navy contractor seeks analytical help from other areas in his company.

ACQUISITION CONSIDERATIONS. Accurate analysis techniques are now available that previously did not exist. This increases the options of doing trade studies and optimization of concepts during the conceptual phase of the design. The techniques can be used to derive specification limits. These techniques are new and are not yet universally available, so there will be an initial learning curve when they are first used. The techniques can be applied to other nonlinear systems with energy storage or sampled systems. They have already been successfully used to investigate problems with ion propulsion engines and ship inertial navigation systems. The techniques can be used to better solve existing Navy problems that, because of complexity, have been previously solved by the test-modify-retest approach.

R&D CONSIDERATION. The new power analysis techniques have to be brought into the Navy and demonstrated as effective in solving Navy problems, and Navy/contractor personnel must be trained in their use. The techniques themselves are strong R&D tools.

2.11 TESTING

DESCRIPTION. Tests are performed for validating a hypothesis such as whether the equipment will operate as intended or for gathering data needed for some purpose such as system integration. The former implies that a hypothesis exists and that the critical parameters for testing that hypothesis have been established. The latter implies that correct data have been measured and are being made available for the intended purpose. Testing is expensive. It is not unusual for testing costs to exceed the cost of the hardware.

STATUS. The lack of effective analysis tools in the Navy has placed the burden for problem solving in EM-Power on test methods that can support the test-modify-retest approach to problem solving. As a result, the Navy and contractors have developed specialized equipment for measuring power systems. Some of these are described in the capability section. The ability to test is the strongest EM-Power capability the Navy has. Even so, this ability is being rapidly overtaken by events: the events being the explosion of economically priced microprocessor-based test instruments and automated data acquisition systems with outstanding testing capabilities. Test equipment developed at the cost of over $100 000 and occupying a 6-foot cabinet can now be outperformed in many respects by a microprocessor-based instrument weighing 15 pounds and available in a GSA catalog for less than $3000.

The lack of availability of good analytical tools has affected the way EM-Power tests are made. In reviewing EM-Power test reports, very seldom does the report develop analytically the hypothesis being tested and the critical parameters needed for decision. As a result, some test programs never measure the critical parameters needed to make rational engineering decisions.

For example, to make a decision on whether the grounding system of figure 2-4 is satisfactory, or whether shielding helps, you need to measure the equivalent output of the generator hull current generator G. In reviewing several tests whose purpose was to evaluate a similar grounding system, about everything but the critical parameter was measured.

The land-based test sites, system integration labs, software development labs, etc, could be used to determine the response of total software/hardware systems to power anomalies. The test sites visited could be easily configured to test for loss of power. However, there appeared to be a strong reluctance to do this, as if it were sensed that this would cause nothing but problems and downtime. As it is, the first knowledge of what happens occurs on the Navy platform when power is first lost. The Fleet experiences the downtime and problems.

Although the Navy and contractors have the capability to test, the required tests often are not made because the critical parameters to be tested are missed or only apparently tested. For example, although the general specification for shipboard electronics, MIL-E-16400G, includes transient testing provisions, the equipment is not required to operate normally during the transient conditions that are expected to occur several times per hour on a ship. The general specification for airborne electronics, MIL-E-5400R, leaves all testing requirements to the detailed equipment specifications.

By contrast, the shipboard fire-control specification, MIL-F-18870E, does contain a sequence that tests all but one of the critical parameters that ensure successful operation aboard ship. The missing critical parameter is audio frequency susceptibility, which is only partially determined by the CS01 test of MIL-STD-461; this CS01 test should always be required, since it detects a frequent fault in power-supply design.

Finally, test data needed during system integration or system modification are not gathered, not delivered to the Navy, or not retrievable by those needing it.

ACQUISITION CONSIDERATIONS. The "system engineering" necessary to assure that proper testing is performed is not reflected in the general specifications. This work has to be done during the validation phase that develops the test requirements. During this phase, the hypothesis to be tested must be selected and the critical tests determined. The various users of data have to be identified and tests developed to provide those data in the required format. Because of the criticality of loss of power, the impact of this should be tested in all acquisition phases including equipment tests, system tests, tests at land-based sites, tests for software changes, and operational tests in the Fleet. The response to common mode noise is another critical test that is often neglected, yet is important for survival in high EM environments.

R&D CONSIDERATIONS. The "system engineering" for adequate EM-Power testing needs to be accomplished and reflected in the general specifications (MIL-E-16400, MIL-F-18870, MIL-E-5400, MIL-STD-454, MIL-STD-461, etc). Methods for the use of land-based test sites for EM-Power testing need to be developed and these methods made part of the test site capability.

2.12 DATA AND DATA BASES

DESCRIPTION. Adequate data are needed for all phases of engineering from conceptual design to system integration and evaluation of system operation. For example, an approximate estimate of total electrical power consumption is needed to size the ship or aircraft electrical powerplant. Power needs that cannot be satisfied by the basic platform electrical power system need to be identified so auxiliary power conditioning equipment such as frequency changers, regulators, transformers, and filters can be determined. Data on harmonic currents and pulsing load currents drawn by individual loads are needed. Data that allow determination of the impact of these harmonic currents and pulsing current loads on the electric power system are needed. Susceptibility data on equipment that describe the sensitivity of loads to electric power system characteristics such as harmonic voltage distortion, voltage transients, and momentary loss of power are needed. Models of the electrical power and load system with good parametric data are needed to determine the impact of waivers and deviations.

STATUS. Data needed for rational engineering decisions related to system integration, system changes, engineering change proposals, evaluation of software changes, waivers and deviations, etc, are just not available. The data needed have usually been measured at some time in the acquisition process but have not been delivered to the government or cannot be located by those needing them. The result is expensive ad hoc tests or engineering decisions made on inadequate data. Engineering decisions made on insufficient data tend to be ultraconservative, adding weight, size, and cost to the system just to be safe. At the EM-Power Workshop (table 1-2), the workshop members emphasized and re-emphasized that they needed better data and retrieval to do their job. The EM-Power task authors spent a disproportionate amount of time looking at the data problem with minimal results because of the apparent lack of structure in how data are collected, stored, and retrieved. The section on specifications discusses the shortfall of data requirements in specifications and standards.

ACQUISITION CONSIDERATIONS. The general specifications are inconsistent in their data requirements. The burden for determining what data are needed, who needs them, what form they need them in, where they will be collected, and how they will be disseminated must be determined in the acquisition cycle, mostly in the validation phase. The penalty paid for lack of adequate data in the acquisition processes is ultraconservative engineering and management decisions. The EM-Power field is not a glamorous field and attracts engineers who are conservative by nature. Mistakes in judgment in EM-Power are highly visible; ie, smoke, fire, noise, destroyed equipment, system downtime, loss of ship electrical power, pilot ejections, etc. The engineer's original conservative existential position is reinforced with his increasing experience. He develops a very low risk-taking threshold. This sequence is unlikely to change and probably shouldn't be changed. The Navy wants solidly designed power systems. However, when there are inadequate data, the decisions tend to be ultraconservative. That is, the best engineering approach is rejected because it appears too risky to be a conservative decision maker. There is a solution to this and that solution is getting the data needed to make the best decision. The present tendency is getting too little data on EM-Power too late in the acquisition cycle to make the best decision. This can be counteracted in the acquisition processes by insisting the best available EM-Power information be obtained at each stage of the acquisition processes and used to make rational EM-Power decisions.

R&D CONSIDERATIONS. The "system engineering" for data collection, formatting, and retrieval should be done. This should be accomplished and incorporated in the general documents such as specifications, contract data requirements lists (CDRLs), and data item descriptions (DIDs), so that they are mutually compatible. Better methods to get these data to the users who need the data are imperative.

2.13 VOLATILITY OF EM-POWER CAPABILITY*

DESCRIPTION. The capability of an organization lies in its people, tools, resources, and organizational structure. The capability can be lost by personnel attrition, obsolescence of tools, dwindling financial support, or a nonfunctional organizational structure.

STATUS. The Navy has a competent capability in EM-Power but that capability is highly volatile and could easily be decimated.

The capability resides primarily in the experience and knowledge of a relatively few people who are in organizations with sufficient tools and resources to support their activities. These people are primarily in the laboratories and field activities, not the SYSCOMs. Most of these activities were represented in the EM-Power Workshop and have a representative on the TESSAC EM-Power team (table 1-2). Several of these activities would lose their significant EM-Power capability if a few (one to three) of their experienced people were lost through retirement, promotion, transfer or death. Probably only three Navy EM-Power organizations could lose up to three experienced EM-Power people without a major or complete loss of capability. These three organizations are the ship platform electrical power RDT&E group at DTNSRDC, the ship power design group at NAVSEC, and the aircraft power component systems test and evaluation group at NATC, Patuxent River. The R&D capability for aircraft power systems would be greatly affected by a three-man loss. All R&D capability for EM-Power in electronics for any platform would be lost if each facility with such a capability suffered a one- to three-man loss.

The capability is easy to lose.

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* The TESSAC technology team leaders were asked to visit personally each Navy laboratory facility having a capability in their discipline and, from what they observed and learned, make a candid assessment of the Navy capabilities. This is a judgmental process that is highly influenced by the content of a few hours of observation and discussion and by the biases of the observer. This section contains most of the judgmental assessments of the EM-Power technology task leader. Any of the members of the EM-Power team would be qualified to make the same visits and draw judgments equally valid as those made here. Those judgments would be different from those given here, at least in emphasis if not in direction. An attempt has been made to make this report as credible and factual as possible. This section mixes opinion and intuition with the facts and the reader is asked to realize this as he reads it. The EM-Power team and their associates form a group of highly professional engineers making substantial contributions to the Navy in EM-Power, often working under difficult circumstances. Hearing them discuss their work, problems, and common goals was a rewarding experience.

In assessing the laboratory capabilities, this story was heard several times: "We had the capability once but when so-and-so retired his replacement had to struggle to get enough work to keep the unit going, so when he retired the unit was scattered."

Once lost, a state-of-the-art EM-Power capability is not easy to regain.

At least two laboratories have attempted, with no success, to obtain a capability in switching regulator power supplies by retraining existing personnel. One laboratory's successful recapture of a lost capability required the hiring from industry of two experienced engineers at the GS-14 level and the transfer of an experienced engineer from another facility. This is not surprising since it has been estimated that there are only about two dozen fully competent power supply designers in the country.[2-27] EM-Power is not a glamorous field to most young engineers, so it attracts few qualified professionals. It is a complex and difficult field requiring a background in nonlinear control theory, circuits, solid-state components, digital control, magnetics, etc. The only formal training is at the graduate level in a few universities. These graduates are in heavy demand by industry. The Navy has yet to capture a fresh-out engineer with up-to-date training in EM-Power. This means that training is by on-the-job experience under the few such experienced engineers the Navy has and by ad hoc short courses. Because of resource limitations and the inability to attract qualified people, these engineers, again with one or two exceptions, are not being trained.

EM-Power investigation capability also resides in analytical and measurement tools. However, no EM-Power facility uses modern state-of-the-art analytical tools in their day-to-day activities although some of these tools are available, and occasionally used, at some facilities.

Measurement tools are generally adequate but are growing obsolete. Funds to replace them are scarce. The most modern facility is the electric power test facility at NATC, Patuxent River, which is a show-case facility, and the laboratory being developed at NADC to support the Advanced Aircraft Electrical System. The cryogenic facility at DTNSRDC is also quite modern.

Except for one or two possible exceptions, funding is a problem for every EM-Power facility. A large portion of the time and energy of the most experienced EM-Power people in the Navy Industrial Funded (NIF) facilities is spent in searching for funds needed for survival. This is one of the tragedies of the system. Survival is such a major problem that the most capable people in the organization have to devote major blocks of time to survival issues rather than solving Navy problems.

The organizational structure for assigning funding, tasks, and responsibilities for EM-Power is complex and the source of many problems. The description of the existing organizational structure and its problems is beyond the resources and scope of this report.

2-27. Power Supply Designers: A Vanishing Breed?, Electronic Engineering Times, Nov 22, 1976.

ACQUISITION CONSIDERATIONS. Competent in-house support in EM-Power topics is scarce and likely to become scarcer in the future unless some better method of supporting the in-house EM-Power capability is devised. This new field is growing rapidly, with contractors making many errors. Maintaining and effectively using competent in-house know-how is important to the successful acquisition of Navy systems.

R&D CONSIDERATIONS. A reasonable and consistent level of R&D support is needed to maintain and improve an in-house Navy EM-Power capability. Tasks to be accomplished include bringing in state-of-the-art analytical capability, replacing obsolete equipment, making sure advances from the Navy or other sources benefit the Fleet, and recruiting and training young professionals in the EM-Power field.

2.14 EM-POWER ISSUES SUMMARY

Thirteen issues in EM-Power are described with status and implications for acquisition and R&D activities discussed.

The most important issues center around loss of mission capability when you most need it, during combat conditions when stresses on the equipment from self-operation and external environments are highest. These survival issues include discontinuity of power (issue 2.1), EMP environments (issue 2.2), structure current coupling modes and susceptibility (issue 2.5), common mode noise rejection in interface circuits (issue 2.6), and shipboard signal grounding practices of doubtful merit (issue 2.7). Mission capability can be lost for hours by power interruptions of a few milliseconds. The EMP environment can result in a loss of power or can destroy or couple false information into interface circuits. Structure currents degrade performance margins if not minimized or if sensitive equipment is not desensitized. High EM environments often enter circuits as a common mode signal, the impact depending on the degree of common mode noise rejection. Signal grounding practices on ships invite problems in high EM environments.

Other issues center around obtaining the initial operational capability. These include system stability (issue 2.4), pulse loads and harmonic currents (issue 2.3), and selection of input power (issue 2.8). The ship and aircraft generators are control loops that interface with other generators (as when they operate in parallel) and with complex loads that contain other control loops (power supplies) that may have negative input impedance (high-efficiency power supplies). The total system has to be and remain stable. Pulse loads can mimic system instability and pulse loads and harmonic currents can distort voltage waveforms to the extent that other equipment is affected. Software changes can cause system malfunctions by changing pulse rates to critical system frequencies. Selecting the wrong input power can add size and weight and failure rate with little or no compensating advantages. This category also has issues that are described in the loss-of-mission category; ie, structure currents, common mode noise, and signal ground.

The final issues center around the effectiveness of getting the job done. These issues include contractor control (issue 2.10), analysis (issue 2.11), testing (issue 2.12), data and data bases (issue 2.13), volatility of EM-Power capability (issue 2.14), and system engineering (issue 2.15). Achieving contractor control (the Navy cost-effectively getting what it technically wants and needs) is unnecessarily complex as presently done. Navy EM-Power analysis capability generally lags the state of the art. Testing capability has been good but is rapidly being overtaken by more cost-effective approaches. Data and data bases are inadequate for the Navy user of data. The Navy capability in EM-Power is mostly in the background and experience of a few senior people. The capability is diverted by NIF funding practices and is highly volatile; much of it could be easily lost.

3.0 STATE OF EM-POWER TECHNOLOGY

There has been a rapid expansion of EM-Power technology in recent years. Aerospace and DoD needs have continued to drive the technology to some extent but a major new thrust has occurred because of the new emphasis on power and energy needs arising from the world energy crisis. The availability of new components from other technologies, as well as improvements in power components, also has had a major impact. This has resulted in new challenges and new funding sources. At the same time, graduate training in the field has increased, the literature base has increased dramatically, and employment opportunities for those working in the field have increased. One result has been a breakthrough in modeling and analysis, which has opened up the possibility of new circuit approaches and new power system architectures, which in turn have stimulated the need for new components. These topics are discussed and then related to the various EM-Power issues.

3.1 IMPACT OF ENERGY CRISIS

Powerplant siting problems and the energy crisis have combined to produce a deterioration in the quality of power grids. Blackouts caused by faults or overloads, and brownouts caused by reduction of voltage to reduce power demand, are becoming more and more commonplace. They have been common for several summers in New York City and similar areas where summer demand outstrips the resources of the local utilities. The same situation developed in New England and California during the oil embargo.[3-1] Transient voltages outside normal voltage limits occur in most utility systems several times a day. Certain critical industrial processes, communication switching stations, and computer installations cannot tolerate these conditions. Table 3-1, reproduced from reference 3-1, summarizes the impact on commercial computer installations.[3-1]

The utility companies are pressing technology to improve the situation[3-2] but conditions will get worse before they get better. Therefore, power users are developing their own solutions by designing power supplies less sensitive to power variations and transients.[3-3]

Uninterruptible Power Sources (UPSs) are also rapidly increasing in use as a solution to the power interruption problem.[3-1, 3-4]

Techniques are being developed to combine nonconventional power sources such as wind-powered generators with power from conventional sources powered by oil, coal, or nuclear energy.[3-5]

3-1. US Department of Commerce Report, The Effects of Electrical Power Variations Upon Computers, 1974

3-2. Gyugyi, L., Reactive Power Generation and Control by Thyristor Circuits, IEEE Power Electronics Specialist Conference Record, 8-10 June, 1976.

3-3. Pioneer Magnetics Catalog No. DP4-76, Brownout Proof Switching Power Supplies.

3-4. Waterman, JJ, Uninterruptible Systems Requirements – A Comparative Analysis, Powercon 1, Beverly Hills, CA, 20-22, March 1975.

3-5. Committee on Aeronautical and Space Sciences, US Senate: Energy-Related Research and Development, US Govt Printing Office, Washington 1974.

TABLE 3-1. SUMMARY OF ENERGY CRISIS IMPACT ON COMMERCIAL COMPUTER INSTALLATIONS*

	I Typical Computer Requirements (at Equipment Connections)	II Typical Utility Power (Delivered at Service Entrance)	III Possible Power Received (at Equipment Connections)	IV Possible Results of Power Problem in Column III
Steady-State Voltage	120/208 volts ± 10 percent, (+ 10 percent, - 8 percent for IBM mainframes)	120/208 volts ± 5 percent	120/208 volts + 1 percent, - 9 percent, resulting from drops between service and equipment	Output errors, unscheduled shutdown, loss of information, costs of downtime, recovery, reruns
Transient Voltage	No dips or surges greater than 20 percent for longer than 30 milliseconds	Large loads coming on-line in vicinity can exceed limits in column I	With possible lower steady-state voltage above, transients could drop voltage beyond limits	Errors, shutdown, possible equipment damage, loss of information, costs of downtime, recovery, reruns
Voltage Continuity	Most computers will not tolerate a loss of voltage for longer than 15 milliseconds	Complete outages exceeding 15 milliseconds can occur from power net switching, lightning	Power discontinuities for longer than 15 milliseconds	Unscheduled shutdown, equipment damage, loss of information, costs of downtime, reruns, recovery
Frequency	60 Hz ± ½ Hz**	Sudden heavy loads can cause a change of 5 Hz or more, but usually frequency is satisfactory †	Adequate frequency received at computer	No effects

*Compiled from discussions with numerous authorities in both the computer and utilities fields
**Some mainframes require 415-Hz power
†Sudden heavy loads on Navy ship and aircraft platforms often cause frequency transients.

Other power conversion techniques that aid conservation allow energy to flow from source to load and, if not used, back to the source.[3-6]

Finally, there is the constant push for increased efficiency in electrical power conversion with switching-mode approaches surpassing other methods in high-efficiency power conversion.[3-7]

3.2 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

The nation's space programs have always needed power conversion techniques that are optimum in weight, efficiency, and reliability. NASA has continually sponsored long-range university research in this area that has yielded both advances in the technology and highly trained personnel who have remained leaders in the field.

For example, the series of NASA research grants to Duke University (Dr TG Wilson) extending over a decade has resulted in approximately 100 published papers in key journals and in alumni with doctorates and masterates still advancing the technology in industry.

Much of NASA's experience is being reflected in a current program, Modeling and Analysis of Power Processing Systems,[3-8] that contains a collection of computer subprograms for designing, analyzing, and optimizing switching-mode power conversion circuitry and total power systems from source to load.

These and related efforts plus a substantial in-house capability have kept NASA the leading government agency in power electronics.

3.3 DEPARTMENT OF DEFENSE

DoD resources used to drive the technology in EM-Power. This is no longer the case. With cutbacks in research and development DoD is now following the technology in most areas, not leading it. The emphasis in EM-Power technology varies from service to service. An adequate assessment of Air Force and Army capability was not made because time and money ran out before the necessary visits for a factual assessment of their capability could be made. Visits to the Air Force Aeronautical Laboratory (AFAL) and the Air Force System Division (AFSD) at Wright-Patterson AFB, Dayton, OH, were made. No visits to the Army were made. Based upon the Air Force and Navy visits and the author's familiarity with reports and papers from the three services, it appears (more an informed guess than a factual assessment) that the Air Force contracts more work than the Navy does and has a much more disciplined and effective way of dealing with R&D contractors. However, because of less in-house technical

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3-6. Middlebrook, RD, the Countertran: A New Controller for Traction Motors, IEEE Industry Applications Society Annual Meeting, Chicago, 11-14 Oct 1976.

3-7. Dilatush, E, Power Supplies – We All Benefit When Their Efficiency Increases, EDN, 5 April 1976.

3-8. TRW Twentieth Monthly Technical Progress Report, Modeling and Analysis of Power Processing Systems, NASA Contract No NAS 3-19690, 1 Dec 1976.

capability (years of experience, hands-on development), the Air Force is more dependent on accepting the contractor's technical viewpoint on what's best. The Army concentrates primarily on power sources (batteries, fuel cells, etc.), which are outside the scope of this report. In EM-Power topics, it appears (again perhaps more a bias or informed opinion than a factual assessment) that the Navy leads the DoD in in-house EM-Power technological capability and yet the Navy technological capability greatly lags the state of the art in most areas.

3.4 UNIVERSITIES

Modeling and analysis techniques have been making major contributions to the state of the art in EM-Power. The advances in these techniques have mainly been made by a few universities, former students of these universities who went on to industry or government, or professionals closely associated with the universities and their graduates. Tracking the work of these universities and their graduates is an excellent way of remaining current with the leading edge of the technology in much of the EM-Power field.

Table 3-2 lists the universities and professors that the author of this report is currently using to track the state of the technology in EM-Power as related to power conversion in electronic systems. This is a dynamic list that will expand.

The members of the EM-Power workshop were asked if they closely followed the work of or used as a consultant any university or professor not on the list. The only additional name was a consultant on high-power solid-state devices used by DTNSRDC.

3.5 COMPONENTS

This section describes some of the advances in components in recent years. No claim is made that the devices given as examples are the leading devices in the technology; they are used to illustrate the general range of components available to design power electronic circuits and systems.

SEMICONDUCTORS. The understanding of bipolar device physics has progressed to the point where the feasibility of proposed transistor designs can be accurately modeled. For example, the maximum collector current that can be obtained can be determined for fixed values of h_{FE}, V_{CE}, BV_{CEO} (SUS), and emitter area. Storage time and forward safe operating area (SOA) can be modeled. This greatly aids the circuit designer in determining whether devices meeting his circuit requirements are possible.[3-9]

Power transistors are available in single-chip junctions (820-mil diameter) with current ratings up to 1200 A.*

VCEO ratings to 600 V with 100-A collector currents and current gains of 100 minimum are available as power darlingtons.**

3-9. Hower, Power Transistor Performance Tradeoffs, IEEE Power Electronics Specialist Conference, Culver City, CA, 9-11 June 19, 75.

* Power Tech Inc, 0-02 Fairlawn Ave, Fairlawn, NJ, 07410; part number PPS1200.

** Toshiba/Solid State Incorporated, 46 Fairand St, Bloomfield, NJ, 07003; part number 2SD647.

TABLE 3-2. UNIVERSITIES IN EM POWER FIELD

1.

University: Duke University, Durham, North Carolina 27706 (Phone: (919) 684-3123)

Professor(s): TG Wilson, HA Owen Jr

Comments: The Duke University program was started by Dr Wilson in 1961. Dr Owens joined the program in 1970. The program is noteworthy because of the length and continuity of the program (16 years), the number of publications in the field (about 100), the number of PhD's trained in the field, and the continuing contribution of their graduates. Duke's program has been concentrated in four areas: the exploitation of nonlinear mathematical analysis techniques in power electronics; circuit investigations, including increased understanding of existing circuits and synthesis of new approaches; the description, use, and design of magnetic components; and the development and application of simulation techniques in power electronics. Dr Wilson was vice chairman of the first Power Electronics Specialist Conference 1970 (then called the Power Conditioning Specialist Conference) and is presently the chairman of the steering committee for the conference. Dr Wilson has conducted a number of ad hoc courses in the field for government agencies.

2.

University: California Institute of Technology, Pasadena, California 91125 (Phone: (213) 795-6811, ext 1822)

Professor(s): RD Middlebrook, Slobodan Ćuk

Comments: The California Institute of Technology (CIT) program was started by Professor Middlebrook in 1971 and is an extension of techniques developed and taught at CIT in design oriented circuit analysis. Because power electronic circuits are exceptionally challenging circuits, they have been used both in developing the techniques and as example problems in illustrating the power of the techniques. The result has been a rapidly increasing number of recent (since 1975) papers making major contributions to the design and analysis of power electronic circuits. The analytical techniques chosen preserve the sense of the circuit topology and start with the simplest analytical model that describes the circuit operation. Analytical complexity is then added only the extent necessary to describe the circuit operation to the accuracy needed for the intended purpose. Accurate measurement techniques have been developed to complement the analytical procedure. Neither the analytical procedures nor the measurement techniques are simplistic but they preserve the essential sense of the circuit that eases the acquiring of insight needed for creative circuit design and building upon what the designer already knows. No long apprenticeship in techniques is needed before the tools become useful, a shortcoming that some of the more mathematically oriented approaches have. Dr Ćuk, who made a major contribution in Power Electronics in his PhD thesis, recently joined the CIT faculty. Dr Middlebrook was Chairman of the 1973 Power Electronics Specialists Conference. He has conducted an ad hoc course in his approach to Power Electronic analysis at the Naval Ocean Systems Center, San Diego, CA, which was attended by a wide cross section of the Navy EM-Power technical community.

TABLE 3-2. UNIVERSITIES IN EM POWER FIELD (Continued).

3.

University: University of Pennsylvania, Moore School of Engineering, Philadelphia, PA 19174 (Phone: (215) 243-8123)

Professor(s): Ralph M Showers, Kenneth A Fegley

Comments: The University of Pennsylvania Moore School of Electrical Engineering in the past has modeled complete aircraft power systems in order to evaluate tradeoffs. They are presently working on a design methodology for predicting and analyzing conducted and radiated interference at frequencies associated with power line frequencies and their harmonics. This is the only known work being done in this area in the academic community on a continuing basis. Portions of the methodology are being used on Navy programs (such as TRIDENT) as soon as they are developed and validated. They are also presently using a model to evaluate the applicability of MIL-SPECS in naval applications.

4.

University: University of Missouri, Columbia, Missouri 65201 (Phone: (314) 882-3491)

Professor: Richard G Hoft

Comments: Dr Hoft initiated their program at the University of Missouri in 1965 when he joined UMC after 15 years in the Corporate R&D Center at General Electric, Schenectady. While with GE he coauthored the first modern book on thyristor inverters (Wiley 1964). This book was translated and published in Japanese (1968) by agreement with Wiley. The power electronics program at UMC has involved research in a broad area of applications including electric transportation systems, appliance controls, regulated power supplies, dc and ac motor drives, and HVDC. The research has emphasized stability analysis, simulation, optimal control, and power semiconductor circuit developments. Ten students have completed PhD's since 1968. During the past 10 years over $250000 in research support has been received, and more than 25 technical articles have been published. There are two regular course offerings on power electronics. These are a senior elective titled "Solid State Power Circuits" and a first year graduate course titled "Thyristor Power Control and Conversion." At present UMC is carrying on an applied research program in solid-state power control funded by a half dozen industrial concerns. The main thrust of this program is MS-level research on new circuit applications of power transistor and thyristor devices. Dr Hoft has taught an ad hoc course at NATC, Patuxent River, Maryland, on inverters, switching regulators, and cycloconverters, and summer short courses at UMC on chopper controlled dc drives and variable frequency inverter - induction motor drives. Dr Hoft was the technical program chairman of the IEEE 1977 International Semiconductor Power Converter Conference and he was honored at the 1977 Power Electronics Specialist Conference as the first recipient of the William E Newell Award for outstanding contributions to the power electronics field.

TABLE 3-2. UNIVERSITIES IN EM POWER FIELD (Continued).

5.

University: Purdue University, Lafayette, Indiana 47907 (Phone: (317) 993-3028)

Professor: LL Ogborn

Comments: Purdue University started its graduate program in Power Electronics a few years ago. It is currently at the master's degree level. Dr Ogborn has taught a course in series and shunt regulator design and a course in switching regulator design at the Naval Avionics Facility, Indianapolis, IN.

6.

University: University of Toledo, Toledo, Ohio 43606 (EE Dept Telephone: (419) 537-2638)

Professor(s): Thomas A Stuart and Adel H Eltimschy

Comments: The University of Toledo started a Power Electronics program in 1975 that goes up through the PhD level. The university offers an on-site masters and doctorate degree program at the NASA Lewis Research Center in Cleveland, Ohio, where a course taught by Dr Stuart has been the best attended to date (29 students). Work presently being performed at the university includes externally sponsored work on a phase control regulator for a superconducting machine and internally sponsored work on an inverter for photovoltaic applications.

7.

University: University of South Florida, Tampa, Florida 33620 (Dept of Electrical Engineering (Phone: (813) 974-2369/2581)

Professor: James C Bowers

Comments: The University of South Florida has no Power Electronics option per se, but offers a number of electives in this area. Also, several of the Professors at USF have considerable background in this field through sponsored research at USF and consulting work. Their cumulative designs in the power field include: Gemini Instrumentation DC to DC Converter and Regulator, GAM 72B Instrumentation Power Supply, Quasi Square Wave Inverter, Minuteman III Logic Power Supply, Minuteman III Memory Power Supply, Viking Computer Power Supply, Space Shuttle Flight Control Electronics Power Supply, and Biax Memory Power Supplies.

In addition, the group has been active in other fields which complement the Power Electronics design work. The SUPER*SCEPTRE simulation program, very useful to this field as well as many others, was developed by the USF team. Other computer programs applicable to the field have been developed. Much work in solid-state modeling for CAD applications has been done at USF. The models applicable to the power field include the complete development of a Hi-Power General Purpose SCR model and a wide range of transistors and diodes. USF is presently completing work on another computer program which automatically generates the nonlinear state-equations from a simple component/node listing of the circuit

TABLE 3-2. UNIVERSITIES IN EM POWER FIELD (Continued).

topology. The complete equations are output along with a simplified terminal model for the complex circuit which has been automatically generated by the program. Dr SJ Garrett and Professor HA Nienhaus have teamed with Dr Bowers on most of these projects.

8.

University: University of Toronto, Toronto, Canada (Phone: (416) 978-2011)

Professor: SB Dewan

Comments: The Power Electronics program at the University of Toronto is probably the largest program, in terms of students and financial support, on the continent. The university has a sophisticated modular structure laboratory that has been used most recently in developing a 250 hp streetcar motor and a power supply for a 100 kW induction heater. Dr Dewan, with Dr A Straughen has written a current text book (1975) that is widely used in Power Electronics graduate courses and ad hoc courses on the same subject. The analysis approach uses Fourier analysis extensively.

9.

University: Delft University of Technology, The Netherlands

Professor: FC Schwarz

Comments: The Power Electronics Laboratory of the Department of Electrical Engineering of the Delft University of Technology, headed by Dr FC Schwarz, graduates about as many trained Power Electronics specialists each year as the total United States academic community. None of these graduates to date works in the USA. Dr Schwarz was formerly with the Electronics Research Center, Cambridge, Massachusetts, and the NASA Lewis Research Center, Cleveland, Ohio. He was Chairman of the 1972 Power Electronics Specialist Conference.

10.

University: Kyushu University, Fukuoka, Japan

Professor: Koojuke Harada

Comments: Kyushu University does research for the Japanese television industry. The university has done the theoretical analysis of a family of switching regulators that efficiently regulate while accomplishing all switching at times where the television receiver used is least sensitive to switching-induced electrical interference. The approach has potential application in some systems where conventional switching regulator circuits might produce unacceptable electromagnetic interference levels.

Transistors are available for less than a dollar with 60-V VCEO ratings and 4-A current ratings, and with switching speeds suitable for 20-kHz power conversions with well specified safe operating areas.*

V-MOS power FETS[3-10] that switch 6 A in less than 10 nanoseconds make power conversion at 100 kHz and higher frequencies possible with conventional switching regulator circuits.[3-11]

Thyristors to 1700-V forward blocking voltage with 600-A RMS current are available, as are devices that handle 2000-A peak sine wave currents at 1200 V and at 5-kHz frequencies.[3-12]

Disc-mounted thyristors to 3100 A and modular assemblies to 7500 A are available.[3-13]

Laser activated thyristors have switched 10,000-A pulsed loads (10μs pulse width) from 1.3-kV lines with rise times of 12 nanoseconds.[3-14] *Gate turn-off devices, thyristors that can* be turned off at the gate as well as turned on,[3-15] and field terminated diodes, thyristor-like devices but with faster turn-off/turn-on and higher dV/dT and dI/dt ratings,[3-16] offer new circuit opportunities.

Schottky-barrier power diodes with less than 10-ns recovery times, forward voltage drops of 0.6 at 60 A, and breakdown voltages of 45 V are available and widely used in low-voltage output switching regulations.**

Diodes with breakdown voltages of 1200 V and current ratings of 650 A with recovery times of less than 1.5 μs are available. ***

High-voltage diodes with ratings of 50000 V and with 150-ns recovery times are available.****

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* Some versions of the 2N3055 or similar chip.

** TRW Semiconductor, 14520 Aviation Blvd, Lawndale, CA; part number SP51.

*** International Rectifier Corp, Semiconductor Division, El Segundo, CA; 651PDL series.

**** SEMTECH Corporation, 652 Mitchell Rd, Newbury Park, CA; part number SFES50K.

3-10. Oxner, E, Will VMOS Power Transistors Replace Bipolars in HF Systems?, EDN, 20 June 1977.

3-11. Electromagnetic Compatibility Optimization of Power Processing System, NASA JPL Contract NAS7-100 with California Institute of Technology funded by the Naval Ocean Systems Center, San Diego, CA, on MIPR N0095377MP09018.

3-12. West Code World, House Journal of Westinghouse Brake and Signal co, LTD, Semiconductor Division, Issue 2, Winter 1977.

3-13. Westinghouse Semiconductor Crusade, Jan 1977.

3-14. Davis, JR, and JS Roberts, Ultra-Fast, High-Power, Laser-Activated Switches, Power Electronics Specialists Conference, 8-9 June 1976.

3-15. Becker, HW, and JM Neilson, A New Approach to the Design of Gate Turn-off Thyristors, IEEE Power Specialist Conference, Culver City, CA, 1975.

3-16. Finke, RJ, et al, A Field-Terminated Diode, IEEE Power Electronic Specialist Conference, Cleveland, OH, 8-10 June 1976.

Complete series pass transistor voltage regulators are available from various sources as monolithic integrated circuits.[3-17] Typical current ratings are 1.5 to 3 A with the flexibility to add additional components to increase the current by a factor of 10 to 100.

Integrated circuits for switching regulator designs are available.[3-18]

Microprocessors are being used more and more as control elements in power electronic circuits and systems.[3-19, 3-20] The 1976 and 1977 sessions of the IEEE Power Electronics Specialist Conference featured evening discussions on microprocessor applications in power electronics.

Fiber optic and optical isolators using gallium arsenide emitters and silicon detectors have long been used in power electronics in place of transformers to isolate signal and power ground for control signals.

PASSIVE COMPONENTS

Aluminum electrolytic capacitors having low equivalent series resistance (ESR) and low inductance have been designed specifically for switching regulator applications, using stacked-foil and four-terminal construction.[3-21]

Solid tantalum capacitors can now be reliably used in power supply filtering applications.[3-22]

Polyvinylidene chloride, a new dielectric, offers lighter-weight capacitors than wet-slug tantalum capacitors and handles high ac currents. Better knowledge of this new film

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3-17. Mattera, L, Powering Up With Linear ICs, Electronics, 3 Feb 1977.

3-18. Mammano, B, Simplifying Converter Design with a New Integrated Regulating Pulse-Width Modular; and C Aswell, A New Monolithic Switching Regulation; POWERCON 3, Beverly Hills, CA; 24-26 Jun 1976.

3-19. 1977 IEEE Industrial Applications of Microprocessors, Philadelphia, PA; 21-23 Mar 1977:
Chen, HH, A Microprocessor Control of a Three-Pulse Cycloconverter.
Rajagopalan, V, et al, Microprocessors in Thyristor Control Application.
Singh, D, and RG Hoft, Microcomputer-Controlled Single-Phase Cycloconverter.
Lin, AD, and WW Koepel, A Microprocessor Speed Control System.
Erusberger, GW, A Microprocessor-Controlled Positioning System Utilizing Thyristors in a *Reversible DC Drive*.
Burger, P, and S Rouchinsky, A Microprocessor-Driven Digital Servo System.
Bose, BK, and KJ Jentzen, Digital Speed Control of a DC Motor with Phase-Locked Loop Regulation.

3-20. Vander Gracht, G, and K Mauch, A Microprocessor-Controlled Three-Phase Inverter, Computer Design, May 1977.

3-21. Boinling, E, Aluminum Electric Capacitors...Notes on Selection and Application, Solid State Power Conversion, Jan/Feb 1976.

3-22. Beck, RL, Solid Tantalum Capacitors in Power Supply Filtering Applications, Solid State Power Conversion, Jan/Feb 1976.

capacitor and other films such as polycarbonate, polysulfone, and polypropylene has greatly increased design options.[3-23]

New computer optimization programs applying Lagrange multipliers to basic inductor design equations and nonlinear programming techniques for more complex circuits allow optimization for weight (given a loss constraint) or for minimum losses (given a weight constraint).[3-24]

New magnetic materials offer improved magnetic devices. Examples are the amorphous metal alloys that may give low-cost alternates to power ferrites at perhaps triple the VA rating.[3-25]

Solid blocks of ceramic-like materials are available that can be used as transformers, filters, capacitors, delay lines, or pulse forming networks. They are being used commercially in thyristor firing circuits but offer many possibilities including, when combined with amorphous semiconductors, solid-material circuits that can perform total power conversion functions with no discrete parts.[3-26]

Application of long-established components such as Mylar capacitors and ferrite beads especially selected for their ac loss characteristics has greatly improved the control of electromagnetic interference generated by switching regulators.[3-27]

3.6 LITERATURE AND CONFERENCES

IEEE POWER ELECTRONIC SPECIALIST CONFERENCE

This conference was established in 1970 and has since been held yearly under various titles: the Power Conditioning Specialist Conference (1970-71), the Power Processing and Electronics Specialist Conference (1972), and the Power Electronics Specialist Conference (1973 and subsequent years). On alternate years it is held East or West of the Mississippi River. The leading edge of the technology is reported in papers of this conference or appears as references in papers presented at the conference. The Interagency Advanced Power Group Power Conditioning Panel holds its annual meeting in conjunction with the conference and most specialists in the field try to attend, if not every year, then on the alternate years when it is closest to them. The proceedings are published yearly. The cumulative proceedings are probably the most complete <u>theoretically oriented</u> "text book" available in the field.

3-23. Chester, MS, and IG Hansen, Description of Magnetic and Capacitor Power Components for Space Applications, IEEE Power Electronics Specialist Conference, Palo Alto, CA, 14-16 June 1977.

3-24. Yu, Y, M Backman, and FC Lee, Formulation of a Methodology for Power Circuit Design Optimization, IEEE Power Specialist Conference, Cleveland, OH, 8-10 June 1976.

3-25. Breakthrough in Magnetic Materials, Solid-State Power Conversion, Mar/Apr 1975.

3-26. NELC TD 167, Independent Research and Independent Exploratory Development 73, Advanced Integrated Material Power Supply, p 66, 1 Sep 1973.

3-27. Bloom, SD, and RP Massey, Emission Standards and Design Techniques for EMI Control of Multiple DC-DC Converter Systems, IEEE Power Electronics Specialist Conference, Cleveland, OH, 8-10 June 1976; reprinted in Solid State Power Conversion, Nov/Dec 1976.

POWER CON

The first Power CON (I) was held in March 1975. Power CON 4 was held in May 1977. Power CON is closely linked to the magazine *Solid State Power Conversion*. Both the Power CON proceedings and the magazine are published by Power CON Inc, PO Box 2445, Oxnard, CA, 93034. The orientation of the conference and magazine is more practical and less theoretical than that of the Power Electronics Specialist Conference. The cumulative conference proceedings and magazine are probably the most complete, practically oriented modern "text book" available. Summary articles in the magazine are an excellent method of tracing component manufacturers and their products.

IEEE INDUSTRY APPLICATIONS SOCIETY ANNUAL MEETING

This yearly meeting presents a significant number of papers on Power Electronics topics, especially on Power Electronics as applied to motor and generator controls. The cumulative proceedings and the related IEEE transactions probably form the best "text books" for Power Electronics related to motors and generators.

OTHER CONFERENCES

The IEEE Conferences on Aerospace and Electronics Systems (along with the IAS above) served as the source of papers in the field before the Power Electronic Specialist Conference and Power CON existed.

The Inter-Society Energy Conversion Conference was established in 1966 and replaced seven individual conferences in the field. This conference concentrates on the technology associated with converting nonelectrical energy (solar, nuclear, heat, light, chemical, etc) to electrical power. The Army-sponsored Power Sources Conference reports primarily on batteries and fuel cells. The main subject matter of both of these conferences is outside the scope of EM-Power, but both conferences have papers with EM-Power topics closely related to the conferences' main thrusts.

The IEEE International Semiconductor Converter Conference, INTERMAG, and the Power Engineering Society Meeting are also conferences of interest.

The foreign conference can be located in the references in papers of the conferences discussed.

BOOKS

Table 3-3 gives a partial list of books of interest to the EM-Power technical community published since 1970.

TABLE 3-3. CURRENT EM-POWER RELATED BOOKS

BOOK	COMMENT
1. RCA Designers Handbook, *Solid-State Circuits,* Technical Series SP-52, RCA Solid-State Division, Somerville, NJ, 08876, 1971.	This book is almost an essential reference for the Power Electronics specialist. It provides essential knowledge for reliable circuit design available otherwise only in widely scattered publications. For example, the section on thermal factors (cyclic thermal stress), equivalent model analysis of power transistors (analysis of inductive load lines), the physical bases for power transition ratings (reverse-bias second breakdown and forward-bias safe area ratings), etc. The major shortcoming is the lack of references to the basic papers providing the technical background for the book.
2. Eugene R Hnatek, *Design of Solid-State Power Supplies,* Van Nostrand Reinhold Company, New York, 1971.	For several years the only book available that corresponded to what designers were actually designing. Still useful.
3. John D Harnden Jr, and Forest Golden (editors), *Power Semi-conductor Applications,* Volumes I and II, IEEE Press, 1972.	A highly useful collection of IEEE reprints grouped in a manner that allows easy location of topics of interest. Equipment Design Considerations: 17 papers under 10 topic headings. Inverters: 23 papers, under 8 topic headings. Power Conditioning for Motors: 27 papers under 12 topic headings. Application by Special Function: 30 papers under 11 topic headings. Application by Industry: 10 papers under 5 topic headings. The introductory comments to each part give an historical perspective to the technology and project technical trends into the future.
4. SB Dewan, and A Straughen, *Power Semiconductor Circuits,* John Wiley & Sons, New York, 1975.	An analytical treatment of inverters and cycloconverters based upon Fourier analysis. Widely used as a textbook in Power Electronic Courses.

TABLE 3-3. CURRENT EM-POWER RELATED BOOKS

BOOK	COMMENT
5. L Gyugi, and BR Pelly, *Static Frequency Changers, Theory, Performance, and Applications,* John Wiley and Sons, New York, 1976.	Deals with a whole family of static ac-to-ac frequency changers in which power conversion is achieved by a single-stage electronic switching circuit without the use of energy storage units. The best-known member of the family is the phase-controlled cycloconverter although this is not the preeminent one from the theoretical viewpoint. The in-depth analysis covers practical circuits as well as circuits awaiting component development before they become practical; therefore, the book lays a theoretical basis for future technology. (Description from introductory material; book was skimmed but not read for this report.)
6. Irving Gottlieb, *Switching Regulators & Power Supplies With Practical Inverters and Converters,* TAB Books, Blue Ridge Summit, PA, 17214, 1976.	This is an easy-to-read book on switching regulators which is deceptively simple, considering the hard-won knowledge and insights into practical design considerations the book offers. This is the book to read for someone wanting an introduction to the field and possibly contains information the expert missed, forgot, or would like to rethink in more complex terms.
7. John M Mott (editor), *Introduction to Solid-State Power Electronics,* Westinghouse Electric Corporation, Semiconductor Division, Youngwood, PA, 15697, 1977.	The basic material was developed by the late Dr William E Newell, a noted authority in Power Electronics. The emphasis is on solid state thyristor circuits.
8. David W Bodle, and Alex J Ghazi, Moinuddin Syed, Ralph L Woodside, *Characteristics of the Electrical Environment,* University of Toronto Press, 1976.	Not read for this review. Skimming the book indicates some material is directly related to the EM portion of EM-Power.
9. LW Ricketts, JE Bridges, and J Miletta, *EMP Radiation and Protective Techniques,* John Wiley & Sons, New York, 1976.	Not read for this review. Skimming the book indicates the book discusses EMP effects on Power-System entry ports.

3.7 EM-POWER ISSUES AND THE STATE OF THE TECHNOLOGY

The issue section (Section 2) discusses the state of the technology for each issue to some extent. The state of the technological solutions to the first three issues is discussed in more detail in this section.

3.7.1 DISCONTINUITY OF POWER

The technical solutions for discontinuity of power include decreasing the probability of failures that interrupt power, adding an Uninterruptible Power System (UPS) to the system, "or"ing power sources at the system/equipment input, and designing-in a self-contained power source. Software approaches are also available.

Designing systems to decrease the probability of failures that can cause a loss of power is done by selecting the best circuit configurations with this criterion in mind, using reliable circuits, using adequate design and safety margins, derating components, and using reliable components. The technology for all of this is available but is often applied in a highly unbalanced manner; ie, high-reliability components are designed into low-reliability circuits. In any event, high system reliability is usually a design objective independent of the discontinuity of power issue. Also, battle damage will still cause loss of power to systems with excellent numerical reliability.

Uninterruptible Power Systems (UPSs) can smooth out voltage variations and maintain voltage to the load when power is lost. The key components are an ac to dc rectifier, battery charger, storage batteries, and a dc to ac inverter. The UPS allows an orderly shutdown of a system or an orderly transition to an auxiliary power source such as a standby diesel or gas turbine driven generator system. The batteries provide power for the 10 to 20 second start-up time for the standby system. UPS systems are expensive; commercial systems cost (in 1973) $400 to $600 per kilowatt for 200 kVA and above systems not including the auxiliary power source.[3-1] UPS systems are often used when they are not the best solution conceptionally. The reason is that they are an add-on component that can be added to systems to rectify original design deficiencies with regard to power interruptions. The UPS will not protect for a shorted load on the bus or bus short between the UPS and the load. It may complicate the hardening for an EMP environment because, besides the power systems and the load, the UPS has to be hardened.

"Or"ing power sources involves bringing two active power sources into the equipment. If either power source is active, the equipment will operate. This technique has been used to maintain power on essential load dc busses. This technique usually involves the use of a "dc link" somewhere in the system. The "dc link" is a dc bus that exists somewhere in the system that can be powered through diodes from multiple sources including batteries. The "dc link" concept can be found in most UPSs, many aircraft power systems, and most submarine power systems. It could be used to a greater extent in electronic systems. Its major disadvantage is that a single load failure can short two power sources. However, this can be protected against to almost any pre-established criterion. Another problem is load hopping, the shifting of load power back and forth between sources in an oscillatory mode. This can be protected against by using control theory concepts or setting one source voltage slightly higher than the other source voltage. Also, when one source fails and the load shifts to the other source, that source exhibits its normal transient response when a sudden load is

applied. Finally, two sets of powerlines must be brought to the equipment and two sets of EMI filters are required. In spite of these problems, "or"ing of power systems is often conceptually the best approach in systems designs where it was never considered.

Self-contained power sources are perhaps the best solution to critical loads that cannot tolerate any power interruptions. Examples are volatile memory systems, inertial platforms, etc. Examples range from the AN/WSN-2 gyro compass system for ships[2-3] to the pocket calculator used now by most engineers in place of a slide rule. The major disadvantage occurs in systems used over a wide temperature range. An inertial navigation system in the F-111 that contains nickel cadmium batteries draws more power at –55°C turn-on to heat the batteries to their –40°C minimum design temperature than the equipment draws for operation. There are also problems with batteries at elevated temperatures. The advantages are that the system can be protected against external failures and battle damage, the system is no more difficult to harden against EMP than a normal system, and it can be protected internally via the best techniques the technology offers at the time the equipment is built; ie, the approach is not dependent on the technology available when the platform was built.

Some systems that cannot tolerate loss of power can be protected by providing power to a few critical circuits rather than the whole systems. In computer based systems, this approach combined with appropriate computer software is often the best solution to power interruption problems. However, it can have a major influence on the computer and system architecture and requires consideration in the conceptual stage and follow-on acquisition phases.

There is a wide variety of technical options available to protect against discontinuity of power. The major problem is managerial, not technical. The problem is getting system designers to adequately address the discontinuity of power issue in the conceptual and following phases of the acquisition cycle.

3.7.2 ELECTROMAGNETIC PULSE ENVIRONMENT

A separate TESSAC report addresses EMP. At the present, the major problem in the context of this report appears to be a managerial problem; that is, convincing the system managers/designers that EMP is real and that problems associated with it can be solved within other program constraints. If the problem is given proper attention at each stage in the acquisition process, the system is likely to be better designed for all EM environments. This report's author found that designing and testing EM-Power circuits for the prompt gamma ray environment was an excellent quality assurance screen for circuit reliability in conventional environments. Circuits that passed prompt gamma radiation tests were rarely an operational reliability problem. Circuits that failed the test had long histories of field failures. Designing and testing for EMP may be equally effective in reducing susceptibility to conventional EM environments.

3.7.3 PULSE LOADS AND HARMONIC CURRENTS

As discussed in the issue section, pulse current loading of the power system is a problem. Solutions within the normal inventory have several drawbacks, and R&D for better approaches is required, especially in radar, sonar, and other high-power systems that operate on a pulse basis. Table 3-4 identifies some of the solution approaches and discusses the status of each.

TABLE 3-4

SOLUTION	STATUS
1. Avoid circuits drawing pulse currents.	Circuit configurations that are functionally equivalent except for pulse current characteristics are available, under development, or conceptually possible. The technological expansion and use of this type circuit provide a partial solution.
2. Tolerate transients and modulation on the power system.	Dissipative regulators become more inefficient as the transient and modulation envelope increases. This is not true of well designed switching regulators. Proper application of switching regulators is a partial solution. Additional transients and modulation on power lines themselves may be an EMC problem that has to be traded off.
3. Changing control loop time constants.	This approach can be used to move system resonances to more desirable locations. As usually done (inadequate control loop analysis and testing), this can be a high-risk approach opening up susceptibility windows that degrade the EM susceptibility of the system. Done correctly (R&D is needed to learn how best to do this), it can be an excellent solution for some problems.
4. Increasing energy storage of energy storage components already in the system.	Where small additional amounts of energy storage are required, this is usually the cost-effective solution. As energy storage requirements increase, other approaches may be more cost-effective.
5. Adding energy storage components to the system that store energy at the system's normal voltages, currents, or frequencies.	Adding motor generators, filters, etc, is a common add-on solution because it is usually the easiest approach. It is brute force approach since energy is proportional to I^2L, V^2C, and mv^2 and the squared variable is not available as an optimizing parameter. Only a small fraction of the stored energy is available to the system. UPSs added to the system may be a more efficient add-on solution depending on the UPS design. Add-on solutions are often selected automatically without much thought. Requiring a simple tradeoff study against other solutions may be an effective management tool to force thinking about other, and possibly better, approaches.
6. Incorporate an optimized energy storage element into the system.	Any system study would probably list this as the first candidate for consideration. It has been little used except in special systems where energy storage is the major technological problem. This is because of past difficulties in transferring energy and maintaining system control and stability. Switching regulator technology now provides an efficient way to transfer energy and new analysis techniques can be used to solve control and stability problems. R&D is required to demonstrate the feasibility in any particular application.
7. Adaptive control system.	Much information is available in the system that is not used by the power subsystem to solve the pulsing current problem. For instance, the pulse template is often controlled by system software.

TABLE 3-4. (Continued).

SOLUTION	STATUS
	This prior knowledge of an upcoming pulse could be used by the power system as well as knowledge about rates of current demand. This knowledge could be used to adaptively control system time constants and the location and amount of energy storage. The control would be a microprocessor. There is considerable precedent for this type approach in industry and utility systems. To the author's knowledge, no one has attempted this approach for Navy systems.

The normal inventory of solutions for harmonic current problems all have some limitations. Some of the solutions are identified and the status of each is discussed in the following table. R&D for better solutions is needed.

TABLE 3-5

SOLUTION	STATUS
1. Multiphase rectification.	Requires transformers that operate at power line frequency that negates size/weight advantages of switching regulators. Larger VA rated transformers needed for given kW rating. Usually used to reduce 5th and 7th harmonics and occasionally the 11th and 13th harmonics. Usually used in conjunction with harmonic traps and low pass filters for higher harmonics. For systems using switching regulators, a better solution is needed.
2. Harmonic trap filters.	A harmonic trap is a series resonant filter in shunt across the power line tuned at the harmonic frequency of interest. Low impedance at this frequency provides a path other than the power lines for this harmonic current. Since the filter attracts harmonic currents from throughout the system, it can actually increase harmonic currents in some branches. Also, a failure of a harmonic suppression circuit anywhere on the power bus can start a chain reaction failure mechanism, failing all the equipment on the power line having harmonic traps. A better solution to the harmonic current problem is needed.
3. Low pass filter.	A low pass filter with acceptable Q over reasonable load ranges is difficult to design. A filter that will reduce the 20% fifth harmonic to the 3% specification limit is considerably bigger than an off-line switching regulator of the same power rating. A low pass

TABLE 3-5. (Continued)

	SOLUTION	STATUS
		filter is impossible or impractical to design for some systems.[3-27] A better solution to the harmonic current problem is needed.
4.	Series-shunt passive filters.	A series-shunt passive filter has been shown to be effective when each filter is designed for the particular application. The filters are relatively large.[2-10]
5.	Active filters.	Active filters are being designed but more R&D for effective designs is needed.[2-11] An all-electronic active filter designed specifically for use with off-line switching regulators in the electronic equipment shows promise, but R&D is required.[2-14]
6.	Tolerate harmonic voltage distortion caused by electronic equipment.	Electronic equipment can be designed to be immune to harmonic voltage distortion. No R&D is required. A relaxation of voltage distortion limits is technically feasible, if nonelectronic equipment can be designed to tolerate harmonic voltage distortion. This has to be traded off against the EMI generated by higher harmonic currents on the power line.
7.	Other.	Other solutions are available. Some of them are discussed in NOSC TD 107.[2-19]

3-27. Kendall, CM, Final Report on the Design and Use of EMI Powerline Filters With Transient Protection For Navy Multiplatform Power Systems, September 1977, Batelle Columbus Laboratory Contract DAA929-76-D-100 for the Naval Ocean Systems Center Code 9234 (Formerly NELC Code 4300)

3.8 STATE OF EM-POWER TECHNOLOGY SUMMARY

There has been a recent rapid expansion of EM-Power technology. The expansion was initiated by the development of new analysis techniques for high-efficiency switched power conversion circuits combined with breakthroughs in semiconductor technology that produced devices capable of fast switching of high voltages, currents, and power. Advances in computer modeling and simulation were also a factor. The criticality of dependable electric power in a sophisticated computer/communications/automation based society has renewed an interest in the technology that produces, distributes, and processes that electrical power. And, finally, the world energy crisis has brought a realization that energy and power should be conserved and efficiently utilized. Wasteful energy conversion and utilization are no longer tolerable.

The result has been a maturing of the technology. Training in power electronics technology is now available in a few (a very few) graduate schools at the Master of Science and PhD level, and a few courses are available to undergraduates. Conferences specializing in the technology have come into existence and it is no longer necessary to scan the wide range of publications for occasional printed articles in the field. At least one trade magazine is completely dedicated to the technology, and other trade magazines regularly publish articles about it. Several books on the technology have been published in the 1970's. In the last decade, power electronics has progressed from "black magic" learned by apprenticeship or experience to an engineering discipline that can be learned in graduate schools or through

published articles and books. There are still relatively few graduate school trained professionals in the field and the Navy has yet to capture its first one.

4.0 EM-POWER TECHNICAL CAPABILITY

The Navy EM-Power technical capability is located in the ten organizations shown in figure 4-1. Four of the seven CNM-commanded laboratories and centers have some technical capability as well as NRL and CEL. The remaining technical capability is in five support functions to the NAVAIR, NAVSEA, and NAVFAC SYSCOMs.

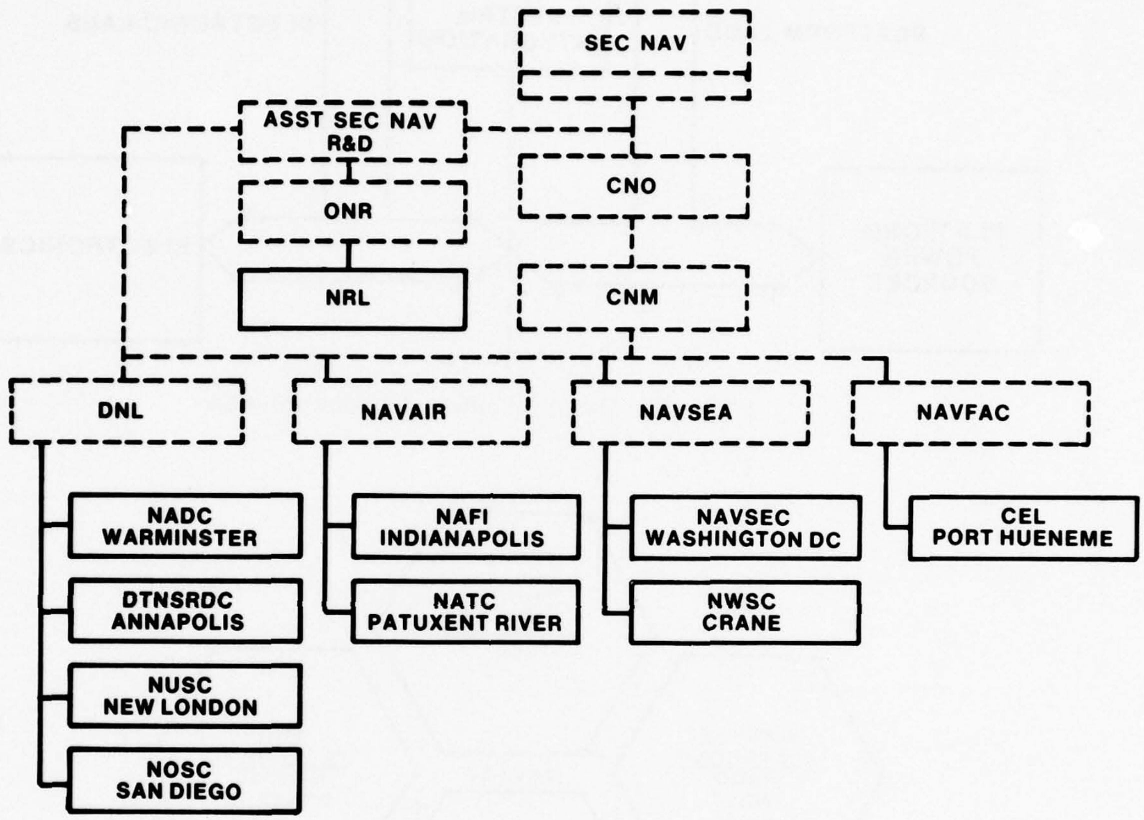

Figure 4-1. EM-power technical capability.

As shown in figure 4-2 the various organizations working in EM-Power are concerned primarily with the electrical side of the power interface or they are concerned primarily as users of electrical power on the electronics side of the interface, or they are concerned with system integration of electronic/electrical loads with the electrical system and with other systems.

The platform/electronics/integration emphasis of the ten organizations is shown in figure 4-3 along with the major SYSCOMs involved.

The criteria for identifying an organization as having an EM-Power capability were as follows. If there were one or more professionals in an organization with an EM-Power charter or responsibility, and they had a good understanding of the technology as it exists today and were using that understanding effectively with respect to Navy EM-Power problems, then the capability was assumed. The number of professionals in an organization comprising the essential capability ranged from one (NRL) to more than a dozen (NAVSEC,

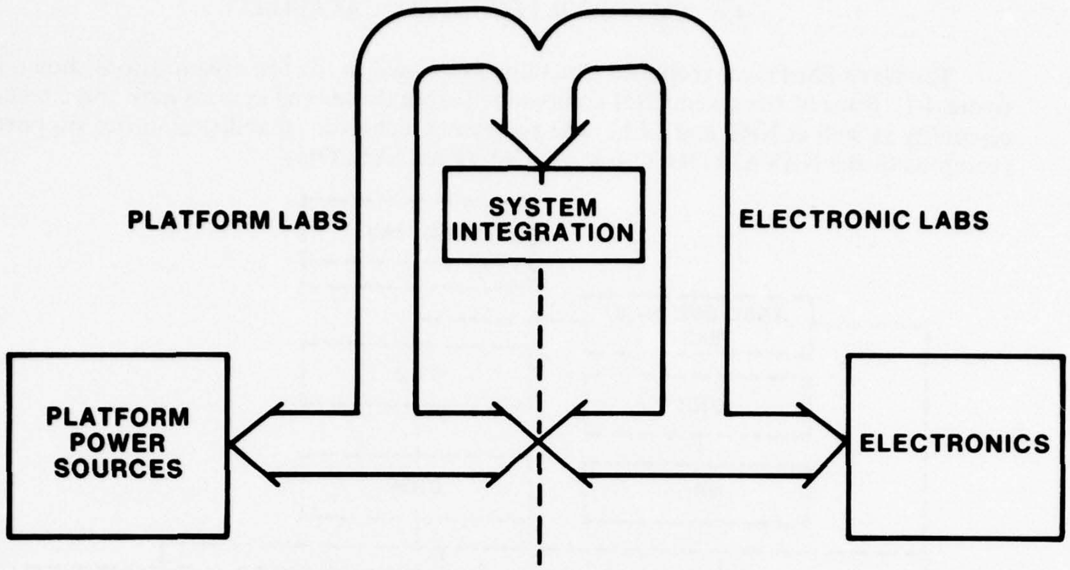

Figure 4-2. Electrical power electronic interface.

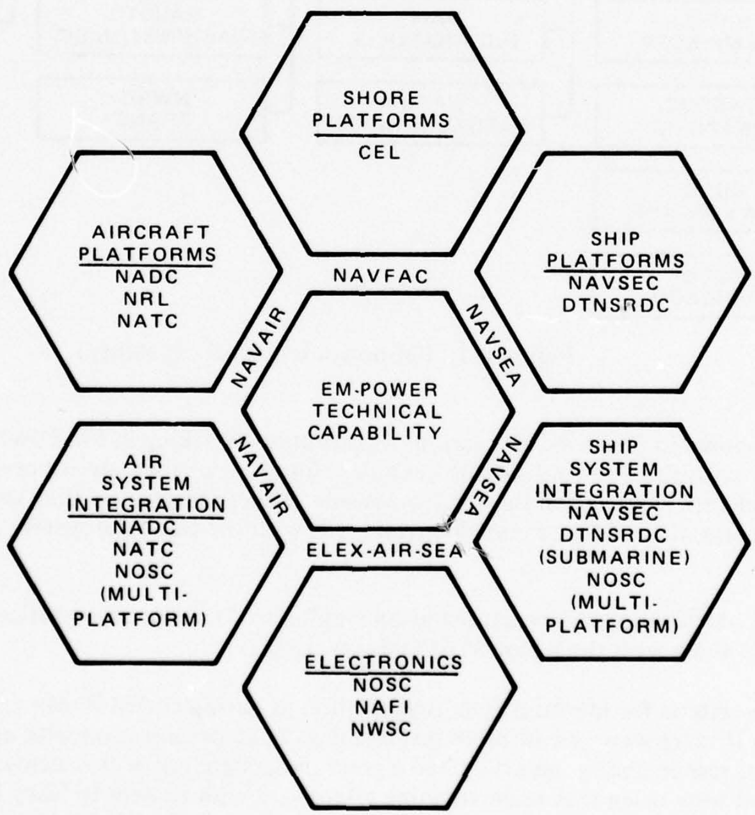

Figure 4-3. EM-power capability, charters, and responsibility.

The capabilities of the several laboratories in the specialty of electric power and power electronics, especially as these relate to electromagnetic considerations (EM-Power), are summarized in this section of the report.

NAVAL AIR DEVELOPMENT CENTER (NADC).

Warminster, PA 18794.

MISSION: NADC is the principal Naval RDT&E center for naval aircraft systems less aircraft-launched weapon systems.

EM-POWER CAPABILITY: This capability is located in the Aircraft Electrical Systems Branch, Aircraft Systems Division, Aeronautical Vehicle Technology Department.

DTNSRDC, NATC), with most organizations having two to four key people. It was found that one or two people could have a substantial impact on overall Navy EM-Power capability.

Each of the Navy capabilities was asked to briefly describe their mission, relate the mission to EM-Power, give a brief description of some capability or recent work, and provide a contact point for further information. These descriptions were edited and are given here. Each organization was also asked to provide a description of some of the analytical and measurement tools they use. These are included in appendix B. They were also asked to identify tools that would increase their capability to do their job. These are given in appendix C. All these data, along with visits to the organizations and the reading of recent reports in EM-Power topics, were used to draw conclusions regarding the capability of the Navy (and others) to solve EM-Power related problems.

4.1 CNM-COMMANDED LABORATORIES

The missions and functions of the Naval laboratories under command of the Chief of Naval Material are defined in reference (4-1). The laboratories are expected to keep abreast of scientific and technical advances in general and to be leaders in areas of unique and special interest to the Navy. The laboratories act as technical advisors to the Chief of Naval Operations, the Commandant of the Marine Corps, the Chief of Naval Material, the Systems Commanders, the designated Project Managers, and others, including the operational forces, on matters within their areas of specialty.

4-1. NAVMATINST 5450.27A, Subj: CNM-Commanded Laboratories and Centers; Missions and Functions of, 22 Dec 1975.

CONTACT POINT: JD Segrest (Code 6073)
Head, Electrical Power Branch
Autovon 441-2354.

FUNCTION: The Aircraft Electrical Systems Branch is engaged in exploratory (6.2) and advanced (6.3) development of airborne electric power components and systems. The EM-Power environment is an important consideration in this effort. Programs representative of areas of expertise include the following:

- Development of engine-driven generators and starter generators together with their required regulation, protection, and control systems. For example, a 270-volt brushless dc generator system with a solid-state control for regulation, protection, and power quality control is now under development.

- Development of solid-state power conditioning and conversion systems and their control and protective interface with the air-vehicle system concept. For example, direct-current to 400-Hz, three-phase, alternating current conditioners rated from 10 kVA to 35 kVA are now under development.

- Development of advanced power distribution concepts. For example, this includes an airborne solid-state electrical logic (SOSTEL) electric-load management system which uses a microprocessor to control all aircraft electric power distribution by means of a digital multiplex data bus. It uses a redundant, distributed-load control center (multiplex/demultiplex units), solid-state power switches, and appropriate software.

- Development of components such as high-power transistors, hybrid power modules, and power controllers. Present projects support the SOSTEL distribution system and high-voltage dc power generation system concepts.

- Development of brushless motors, fractional and integral horsepower, to operate from 270 volts direct current.

- Development of a flat-bus, power-distribution cable with branch-circuit terminations. The objective of this development is reduction in weight together with improved EM-Power characteristics.

- Development of an Advanced Aircraft Electrical System (AAES). This is an advanced development (6.3) power system concept including SOSTEL power distribution, 270-V dc advanced power generation, and the GPMS (general-purpose multiplex system) – a MIL-STD-1553, poling contention, digital data-handling system.

Major facilities of the branch include the AAES integration laboratory. This laboratory provides a hot mockup of the aircraft electric power system, distribution system (SOSTEL), data system (GPMS), and avionic systems. Advanced systems integrated at this facility include armament, flight-control, display, and core avionics. This facility provides a V/STOL laboratory for advanced system integration and EM-Power compatibility evaluation. The facility includes a shielded enclosure for evaluation of EM characteristics of hardware and systems.

Other facilities available at NADC include the P3 software center, the S3 avionics system laboratory, and the BASIC avionics system integration operation. EM-Power characteristics, such as power interruption, may be addressed in these facilities but complete power-system integration capability is not provided.

DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER (DTNSRDC).

Bethesda, MD 20084.

MISSION: DTNSRDC is the principal Navy RDT&E center for Naval vehicles and logistics and provides RDT&E support to the US Maritime Administration and the maritime industry.

EM-POWER CAPABILITY: Electrical systems for Naval vehicles come within the purview of DTNSRDC. Included are the generation, control, conversion, and distribution of electrical power and those facets involved in the delivery of regulated power to radars and weapon systems.

This capability is located in five specific areas within DTNSRDC's Propulsion and Auxiliary Systems Department (Code 27).

CONTACT POINT: Dr Harold R Boroson, Code 278
Head, Systems Integration Division
Autovon 278-2857.

FUNCTION: Functions and capabilities provided in each of the specific EM-Power related are reflected in the organization of the Systems Integration Division, which is composed of five branches. Among the more than 50 engineers and scientists in the division are many with knowledge in areas directly related to EM-Power. Most of these personnel are in the Electrical Systems Branch. The rest are in other Branches of the Division and in other Divisions of the Department.

Electrical Systems Branch. (Code 2781, Contact: CR Young, AV 278-2557.) The primary function of this branch is to improve the generation, control, conversion and distribution of Naval ships' electrical power to provide power to Naval weapon systems. Approximately 15 engineers in this branch have knowledge in areas related to these specific functions. Studies have been conducted and improvements have resulted from such studies as power system harmonics, short- and long-term voltage transients, voltage and frequency regulation, modulation, and noise. Computer simulations of system components such as turbine generators and solid-state power-conversion equipment have been completed and plans have been made to simulate an entire electrical power system prior to its installation aboard ship. Dynamic load simulators developed at DTNSRDC are used to investigate the effects of radar type nonlinear, pulsing loads on electrical power systems. Power-conversion equipment such as solid-state frequency changers and motor-generator sets is also evaluated under simulated radar load conditions, during development and prior to shipboard installation. A complete simulation facility for the investigation of electrical/electronic interface compatibility is being developed. Various electronic loads and electrical power systems and equipment will be investigated.

Motors and Components Branch. (Code 2771, Contact RJ Flaherty, AV 281-2079.) This branch conducts research and development on electrical motors and generators. This work includes starters, brushes, and other motor components. Research and development is also conducted on special problems of wound components such as motors, generators, and contactors. This branch places emphasis on problems in which electrical design is inseparable from insulation and other parameters of wound components.

Electrical Transmission Branch. (Code 2772, Contact: G Rodriguez, AV 281-3118.) This branch conducts research and development on means for transmitting 60- and 400-Hz electrical power to meet requirements dictated by new functions and new technology. Emphasis is placed upon obtaining desired electrical characteristics while reducing weight and increasing fire and water resistance and handling ease. Cables, waveguides, and associated fittings are under development to carry wideband high-frequency power and to meet new or extended parameter requirements.

Semiconductors Branch. (Code 2773, Contact: WH Kohlman, AV 281-2526.) This branch conducts research and development in the characterization and application criteria of solid-state devices for ship and submarine electrical power systems. It develops new techniques and facilities to measure solid-state device characteristics under combinations of electrical and physical stresses.

Physical Office of Superconductivity. (Code 2722, Contact: JH Harrison, AV 281-2423.) This office plans and manages research and development of superconduction electrical propulsion power systems, related equipment, and the supporting technology. The office maintains technical communications with other Government activities as well as with industrial research groups and universities working on electrical power generation using superconductors. The development of superconducting motors has advanced to the point where application of superconducting propulsion power systems for future ships is almost a certainty.

NAVAL OCEAN SYSTEMS CENTER (NOSC).

San Diego, CA 92152.

MISSION: NOSC is the principal Navy RDT&E center for command control, communications, ocean surveillance, surface and air launched undersea weapon systems and supporting technologies.

EM-POWER CAPABILITY: This capability is located in the Power Electronics Branch (Code 9234).

CONTACT POINT: J. Foutz, Code 9234
Head, Power Electronics Branch
Autovon 933-2752

FUNCTION: Power Electronics Branch. The Power Electronics Branch is responsible for the development and implementation of state-of-the-art concepts, techniques, and methodology associated with power-electronics technology as used in electronic equipment. The branch consists of seven professionals. Two additional power specialists outside the branch (JF McCartney, Code 63103, and LJ Johnson, Code 8112) contribute to NOSC capabilities in the field of EM-Power. Branch capability is concentrated in four areas: switching regulator technology as used in electronic equipment and systems; the electric power/electronic interface as viewed from the electronics side of the interface; power electronics analysis and control techniques including computer modeling; and advanced material concepts related to power electronics.

Examples of switching regulator technology programs include the Reduction of Shipboard 400 Hz Power Requirements Program, which showed that 60- to 400-Hz frequency changers could be eliminated by exploiting the use of switching regulator power supplies in

shipboard electronics, and the Standard Electronic Module (SEM) Power Supply Development Program, which is developing a family of switching regulator power supplies for the Navy SEM program.

Examples of electric power/electronic interface programs include the development of the criteria for determining when EMI filters and switching regulator combinations will oscillate (published in IEEE publications and MIL-HDBK-241) and the technical coordination of the development of EM-Power analytical tools in the DDF funded EMX program. The preceding are also examples of power electronics analysis and computer modeling tasks, as is a program to model microwave tubes by computer simulation as an aid in design improvements that will increase their reliability. The advanced material program is centered on developing complete switching regulator power supply circuits in monolithic materials that, unlike silicon, have energy storage capability. The goal is to completely eliminate discrete parts including transistors, diodes, inductors, transformers, and capacitors, thereby accomplishing the power supply function in a solid block of material.

The Power Electronics Branch exploits the capabilities of universities, industry, and other Navy and government facilities to the greatest extent possible using its own personnel resources for concept development and as technical advisors and consultants in Power Electronics.

NAVAL SURFACE WEAPONS CENTER (NSWC).

Silver Spring, MD 20910.

MISSION: NSWC is the principal Navy RDT&E center for surface ship weapons systems, ordnance, mines, and strategic systems support.

EM-POWER CAPABILITY: Electromagnetic pulse (EMP) effects on power systems.

CONTACT POINT: Dr RJ Haislmaier, Code WA 51
Head, EMP Branch
NSWC, White Oak, MD.
AV 290-1743

NAVY UNDERWATER SYSTEMS CENTER (NUSC).

Newport, RI 02840.

MISSION: NUSC is the principal Navy RDT&E center for submarine warfare and submarine systems.

EM-POWER CAPABILITY: This capability, as related to the electromagnetic compatibility of submarine electronic systems, is located in the Electromagnetic Systems Department, Code 34.

CONTACT POINT: David McQueeney, Code 344
Head, EMC and EM Systems Support Division
Autovon 636-2534.

FUNCTION: The Electromagnetic Compatibility Support Division provides centralized support to NUSC product lines in the EM-Power–EMC area. Four personnel are primarily associated with the EM-Power area:

PJ Johnson, Code 344, AV 636-2626
GJ Majewski, Code 344, AV 636-2317
GC Barker, Code 344, AV 636-2629
D Dixon, Code 344, AV 636-2453

Some specific areas of the power-EMC effort addressed by Code 344 under the TRIDENT program, as directed by NAVSEC 6174D, include low-frequency induction-field radiator and susceptor models, shielding at power frequencies, low-frequency grounding requirements, and cable-coupling problems. The basic power-EMC capability at NUSC is augmented in EMC areas by approximately 10 other personnel who have some knowledge of or experience with power-EMC problems.

NAVAL RESEARCH LABORATORY (NRL).

Washington, DC 20375.

MISSION: Conduct a broadly based multidiscipline program of scientific research and advanced technology development directed toward new and improved material, equipment, techniques, systems, and related operational procedures for the Navy.

EM-POWER CAPABILITY: This capability is located in the Electronics Technology Division.

CONTACT POINT: B James Wilson, Code 5210.3
Autovon 972-3357

FUNCTION: NRL is treating the interrelationship between electrical power systems and electromagnetic environments in conjunction with the formulation of new standards for aircraft electrical systems. The Naval Air Systems Command has Department of Defense cognizance for aircraft electrical power and has tasked the Laboratory to serve as custodian for the modernization and maintenance of MIL-STD-704, Aircraft Electrical Power Characteristics. The need for this document to treat electromagnetic effects has led to a continuing program of measurements of systems-conducted interference and concomitant instrumentation developments, the latter stressing digital-data processing. It has also resulted in a program of liaison and coordination among Army, Air Force, and the United States electrical systems community. Verification of new measurement techniques is carried out through onboard tests at NATC following initial laboratory determination of feasibility at NRL by theory, computer, and breadboard studies, or tests on prototype equipment at NADC and NATC.

CIVIL ENGINEERING LABORATORY (CEL).

Port Hueneme, CA 93043.

MISSION: CEL is the principal Navy RDT&E center for shore, fixed-surface, and subsurface ocean facilities for the Navy and Marine Corps construction forces.

EM-POWER CAPABILITY: This capability is located within the Electrical and Electronics System Division.

CONTACT POINT: Evo Georgi, Code L62
Director, Electrical and Electronics Systems Division
Autovon 360-05690.

FUNCTION: The objective of the work at CEL is to solve problems associated with the supply of electrical power to Naval installations. There are eight professionals and two support personnel. These persons serve as consultants to Navy and other Department of Defense agencies on a wide variety of problems in the EM-Power field. In addition, in-house ongoing research is conducted in solid-state power electronics and power conditioning areas to maintain expertise in EM-Power.

A representative EM-Power program at CEL is the recently completed major R&D program called the HIGH QUALITY POWER PROGRAM. The first accomplishment of this program was the development of a power-line transient monitoring and recording equipment which was capable of extremely rapid response and accurate reproductions of waveform disturbances on a continuous basis over long periods of time. The next accomplishment was the development of power-line, transient-simulation equipment capable of simulating transients, surges, sags, frequency excursions, and momentary outages. This equipment was used to perform susceptibility tests on suspected electronic equipment to ascertain the vulnerability of that equipment to the various power-line aberrations. These equipments have been used extensively over the years to assist organizations experiencing EM-Power problems. Many refinements to the equipment and measurement techniques have been made. These have resulted in smaller, more economical monitoring equipment and in concepts which have been picked up by industry and are now marketed as commercial items. Technical reports are available of past work and programs in EMC, EMP, and other EM-Power-related programs accomplished by CEL.

4.2 OTHER CNM COMMANDED FACILITIES

In addition to the research activities just discussed, there are four CNM facilities which are active in the EM-Power area.

NAVAL SHIP ENGINEERING CENTER (NAVSEC).

Washington, DC 20362.

MISSION: Perform assigned engineering and material management and material requirements in support of the Naval Sea Systems Command; responsible for the support of program requirements for ship design, system and equipment design, installation and maintenance engineering, procurement, and material management.

EM-POWER CAPABILITY: This capability is located in the Machinery Systems Division, The Combat Systems Design and Integration Division, and the Ship Design Division.

CONTACT POINT: For EM-Power where the emphasis is on electrical power.

FL Henrickson, Code 6156D
Head, System Analysis Section
Autovon 222-6062.

For EM-Power where the emphasis is on EMC.

Frances M Prout, Code 6174D
Head, Electromagnetic Performance/Compatibility
Section
Autovon 222-3674.

FUNCTION: Machinery Systems Division. The division (Code 6140) is responsible for the design, development, installation, operation, and maintenance of shipboard propulsion machinery, auxiliary systems, and electrical power and distribution systems. The division efforts are coordinated with those of other systems commands to install weapon systems, aircraft-related systems, and submarine life-support systems.

Combat Systems Design and Integration Division. The division (Code 6170) is responsible for the development, design, procurement, and maintenance engineering of shipboard electronic systems in the areas of radar, submarine antennas, interior communication, computer, navigation, and weapons control. The division is responsible, on a whole-ship basis, for the design and integration into the ship of all shipboard electronic equipments and systems including, in addition to the just-mentioned equipments and systems, the Navy Tactical Data Systems (NTDS), command control, ordnance, and sonar.

Ship Design Division. The division (Code 6110) is responsible for directing, managing, obtaining financial resources for, and preparing new total ship designs and major conversions as requested by appropriate authority.

NAVAL AIR TEST CENTER (NATC).

Patuxent River, MD 20670.

MISSION: Perform test and evaluation of the total aircraft including aircraft mission systems, aircraft systems, aircraft mission equipment, subsystems, components, related support systems, and integrated logistic support elements. Provide technical advice and assistance to the Naval Air Systems Command, the Board of Inspection and Survey, other Government agencies and contractors. Assist other RDT&E and OT&E activities in fulfilling their mission requirements. Conduct test-pilot training and in-house technical projects which develop and document test and evaluation technology.

EM-POWER CAPABILITY: This capability at NATC is located in the Systems Engineering Test Directorate.

CONTACT POINT: For EM-Power where the emphasis is on electric power.

GR Danks, Code SY60
Electrical Systems Branch
Autovon 356-4701.

For EM-Power where the emphasis is on electronic system integration.

RF Lane, Code SY80
Electronic Systems Branch.

FUNCTION: Electrical Systems Branch. The branch (Code SY60) conducts laboratory and flight evaluations of aircraft electrical power generation, conversion, and distribution systems and system components. The capability of the branch in the EM-Power area results from its technical ability to closely simulate electrical-power system operation in the laboratory, to make appropriate EM-Power measurements, and to obtain aircraft data when these measurements must be made in flight. A recent example of a branch project is the laboratory and flight evaluation of the A-4M aircraft variable-speed, constant-frequency generating system. A complete electrical and environmental evaluation was performed in the laboratory where all expected flight operating conditions were simulated. Following this effort, the system was fully instrumented for in-flight measurement of all meaningful steady-state parameters during representative combat flight profiles. Various system electrical, mechanical, and cooling modifications were later evaluated to determine their effect upon system performance.

Electronic Systems Branch. The branch (Code SY80) places EM-Power emphasis on electronic systems and components which interface with the power system.

NAVAL AVIONICS FACILITY (NAFI).

Indianapolis, IN 46218.

MISSION: Conduct research, development, engineering, technical evaluation, pilot and limited manufacturing and depot maintenance on avionics, missile, shipborne, and related equipment.

EM-POWER CAPABILITY: This capability at NAFI is located in the Applied Research Division, Code 830, and in the Test and Evaluation Division, Code 440.

CONTACT POINT: JH Jentz, Code 835
Electronics Systems Branch
Autovon 724-3927

FUNCTION: Electronics Systems Branch, Code 835. The major area related to EM-Power is the design, development, and procurement of power supplies which are used in Navy submarines, ships, aircraft, missiles, and shore-based equipments. Specific areas of power-supply design and analysis expertise include series regulators, switching regulator power supplies, magnetics, EMI suppression, and packaging techniques. R&D work is primarily directed at improving switching regulator design and analysis techniques. Within the framework of the Standard Electronic Modules (SEM) program, under NOSC program and technical management, the branch has the responsibility to let an industry contract for the development, procurement, and SEM qualification of a fully documented family of SEM power supplies for multiple-platform use. Under the sponsorship of NADC, the branch is involved in the in-house development of a 270-V dc solid-state Remote Load Controller (RLC) for the Advanced Aircraft Electrical System (AAES) program.

Test and Evaluation Division, Code 440. (Contact: D Fassburg, AV 724-3986.) Performs required EMI/EMC and power military-specification tests on in-house and some contractor-developed military equipments. This group has developed computer-aided design and analysis techniques for shielding and power filters.

NAVAL WEAPONS SUPPORT CENTER (NWSC).

Crane, IN 47522.

MISSION: Provide material, technical, and logistics support to the Navy for ships and crafts equipments, shipboard weapons systems, and assigned expendable and nonexpendable ordnance systems and perform additional functions as directed by COMNAVSEASYSCOM.

EM-POWER CAPABILITY: This capability is located in the Engineering Branch of the Weapons Quality Engineering Center (Code 30).

CONTACT POINT: Robert VanWinkle, Code 3026
Engineering Branch
Autovon 482-1252

FUNCTION: The main emphasis at this organization is on providing technical inputs to Military Standards. For example, MIL-STD-241, A Design Guide for EMI Reduction in Power Supplies, was authored by this organization. MIL-STD-241 addresses the design of EMI filters and other topics related to EMI problems with power supplies such as component selection, layout, and shielding. This organization has also provided technical input to MIL-STD-461 and MIL-STD-220 studies.

4.3 INFORMA[illegible] EXCHANGE/COORDINATION

INTERAGENCY ADVANCED POWER GROUP (IAPG)
POWER INFORMATION CENTER
3524 SCIENCE CENTER
PHILADELPHIA, PA 19106 (215) 382-8683

EM POWER CAPABILITY: ELECTRICAL WORKING GROUP, POWER CONDITIONING PANEL, SUPER CONDUCTIVITY PANEL, MAGNETOHYDRODYNAMICS WORKING GROUP, MECHANICAL WORKING GROUP, SYSTEMS WORKING GROUP.

DESCRIPTION: This agency was created solely for use by and benefit to the US Government. Its purpose is to effect an exchange of information at the technical level on R&D programs in the electric power field. At present, it is jointly funded by the Army, Navy, Air Force, National Aeronautics and Space Administration, and the Energy Research and Development Administration. Liaison is maintained with the Office of the Secretary of Defense, National Sciences Foundation, Department of Transportation, and the Department of Health Education and Welfare.

Energy/power technical disciplines covered by the IAPG working groups and panels include chemical, electromagnetic, magnetohydrodynamics, mechanical, nuclear, solar, photovoltaic, solar thermal, thermoelectric, thermionic, superconductivity, and power conditioning. A new systems working group has been formed to consider complete electric power systems from source to user and system analysis methodology and results.

Two principal modes of information exchange exist. One is the distribution of project information in the form of briefs to subscribers both inside and outside the government. The other takes the form of periodic meetings among governmental personnel with kindred technical interests.

Current Navy IAPG participation is shown in table 4-1.

TABLE 4-1. NAVY IAPG PARTICIPATION (JUL 1977).

Navy Activity	Steering Committee	Electrical Working Group	Power Conditioning Panel	Superconductivity Panel	Magnetohydrodynamics Working Group	Chemical Working Group	Mechanical Working Group	Nuclear Working Group	Solar Working Group	Systems Working Group
ONR	x	x		x	x	x	x	x		x
NAVMAT	x									
NRL		x	x	x	x	x		x	x	x
NADC						x	x		x	
NCSL							x			
NOSC		x	x			x			x	x
DTNSRDC		x	x	x		x	x			x
NSWC						x		x		
NUSC										
NWC										
NAVAIR							x		x	
NAVELEX						x		x		
NAVFAC										
NAVSEA		x		x	x	x	x	x		
NAVSEC		x	x	x	x	x		x		x
MARINE CORP HQ						x				
NWSC						x				
NISC		x	x	x	x	x	x	x		x
NWC		x				x	x		x	x

4.4 OTHER CAPABILITIES

Additional information on capabilities of universities and the NASA and DoD in general is presented in the 3.0 State of EM-Power Technology section of this report.

4.5 EM-POWER TECHNICAL CAPABILITY SUMMARY

The Navy EM-Power capability is located in ten Navy organizations. An eleventh organization specializes in EMP. These organizations and their primary mission/capability are:

	Research and Development	Test and Evaluation	System Integration (RDT&E)
NADC	Aircraft Power	Aircraft Power	Aircraft
DTNSRDC	Shipboard Power	Shipboard Power	Ships/Submarines
NOSC	Electronics	–	Multiplatform, EMX
NUSC	–	–	Submarines
NRL	Aircraft Power	–	–
CEL	Shore Power	Shore Power	–
NAVSEC	Shipboard Power	Shipboard Power	Ships/Submarines
NATC	–	Aircraft Power	–
NAFI	Electronics	Electronics	–
NWSC	Specifications	–	–
NSWC	EMP	EMP	–

The Navy capability in many areas is dependent on one or two key people. The EM-Power capability would be lost to the Navy facility if these key people were lost. (This is not unusual in EM-Power. It was found to be also true of the universities and most contractors.) Details of the existing Navy capability and needed capabilities are given in appendix B and C.

The leading government agency in EM-Power is NASA.

The status of R&D activities in the various government agencies active in the field is discussed in the Inter Agency Advanced Power Group, a group existing for the sole use and benefit of the government.

5.0 ADEQUACY OF EM-POWER SPECIFICATIONS AND STANDARDS

5.1 PURPOSE OF SPECIFICATIONS AND STANDARDS

The Navy procures its materials (ships, aircraft, weapon systems, computers, etc) by means of contractual documents. In these documents, it is necessary to describe the requirements placed on the procured material and the methods used to determine that the requirements are met (quality assurance). Specifications and standards (S/S)* are used to describe the requirements and the quality assurance provisions placed on the material by the contract. Usually a top-level specification, unique to the product being purchased, is used that calls out general specifications and standards in a hierarchy arrangement. This use of specifications and standards is efficient in communicating the characteristics of the wanted material and in achieving effective contractual control. The statement, "The equipment shall operate from electrical power with the characteristics of MIL-STD-1399 Section 103, Type I, 440V, 60Hz, three phase," is equivalent to a 17-page description of shipboard electrical power which includes eight figures. The contractor is familiar with this 17-page description and knows what he must do to meet its requirements. This approach is also efficient in obtaining effective contractual control since the standard is, at least in theory, the quintessence of the Navy's experience over a period of years with many contractors in describing the shipboard ac electrical power interface in contractual terms.

This section of the report examines the adequacy of specifications and standards for assuring that procured systems function as intended in electromagnetic environments associated with EM-Power. A systems approach is used in this examination.

5.2 SYSTEMS APPROACH TO SPECIFICATIONS AND STANDARDS.

A system viewpoint is used to develop criteria for determining the effectiveness of specifications and standards controlling EMC on the power/electronics interfaces. Since a "system viewpoint" can mean different things to different readers, the concept as used here is discussed.

The total system is first defined by a boundary or a universal set. Subboundaries or subsets are then defined within the total system or universal set. One of the main tasks of system engineering is to define easily controlled subset boundaries and then to control these boundaries (or interfaces) effectively. Specifications and standards are used for this control.

For example, figure 5-1 defines a system boundary consisting of the electrical power system and two electronic systems that interface with the power system and with each other. The electrical interface between the electrical power system and electronics system is

* Specifications and standards are defined and discussed in more detail in appendix D.

controlled by several specifications, including MIL-STD-1399 Sec 103,[5-1] MIL-STD-461,[5-2] and MIL-E-16500.[5-3] Effective control of the interface requires that these specifications and standards be mutually compatible. The two electronic systems are electrically connected by a signal common. There is little control of this important signal common interface in the general specifications and standards.

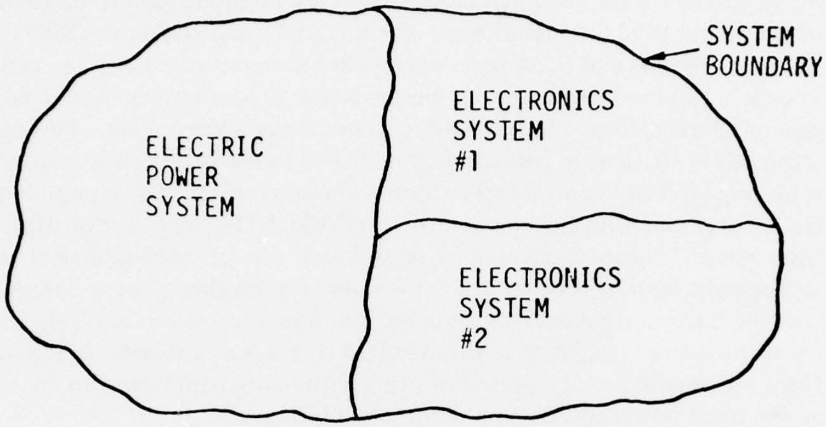

Figure 5-1. Example of system defined by a boundary and partitioned into subsystems by subboundaries

Another example of the system approach is shown in figure 5-2. Of all possible data that could be collected about a system, the Navy has a need for one subset; the contractor generates a second subset and delivers a third, smaller subset to the Navy. Effective technical and contractual control would require the control of subset boundaries so that the data needed are within the boundaries of the data delivered.

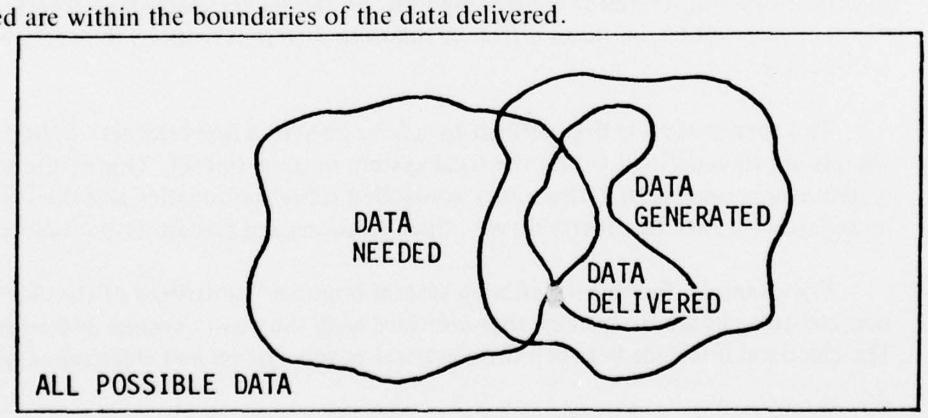

Figure 5-2. All possible data partitioned into three data subsets

5.1 MIL-STD-1399A (Navy), Interface Standard for Shipboard Systems, Section 103, Electric Power, Alternating Current, 1 Dec 1970.

5.2 MIL-STD-461A, Electromagnetic Interference Characteristics, Requirements for Equipment, 1 August 1968

5-3. MIL-E-16400G (Navy), Electronic Interior Communications and Navigation Equipment, Naval Ship and Shore, General Specification for, 24 Dec 1974.

A specification tree, figure 5-3, is another systematic way of displaying relationships.

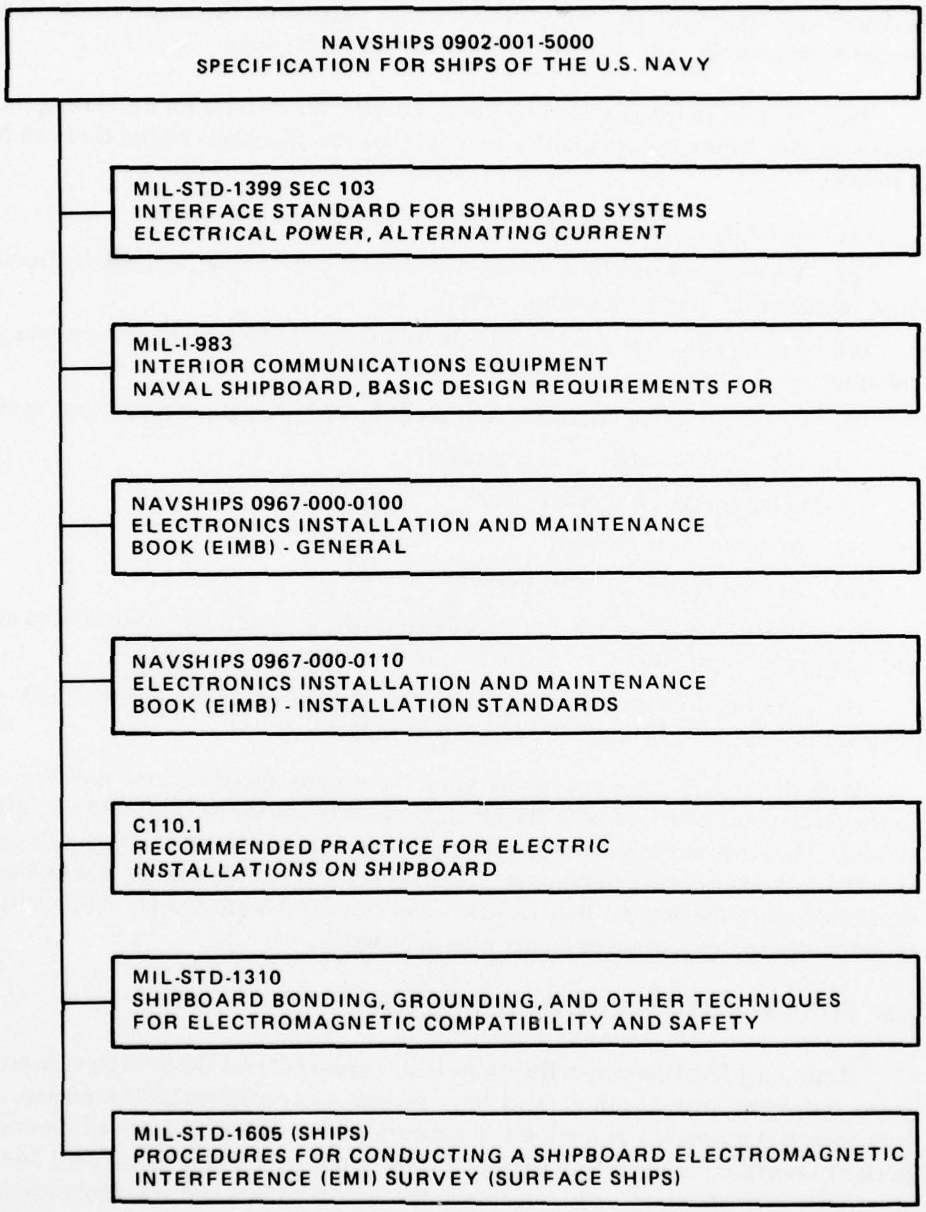

Figure 5-3. Specification tree, NAVSHIPS 0902-001-5000

Similar approaches can be used for other interfaces of interest such as performance (needed, specified, achieved), technology/specifications, and the Navy/contractor contractual interface. A characteristic of this approach is that no single specification or standard is necessarily identified as ineffective by itself; however, the relationships can be identified as ineffective. Which specification or standard to change to improve the situation often requires technology considerations. For example, whether the power systems specification or electronics specifications should be changed may depend on the relative state of the art of generator technology and electronic power-supply technology.

This "system viewpoint" can be used to define the criteria for evaluating the effectiveness of specifications and standards. Examples of specification criteria that can be used are as follows:

(a) Is the interface controlled by specifications or standards?

(b) Are conjoint specifications and standards compatible (amplitude, frequency, phase, bandwidth, design philosophy, etc)?

(c) Are specifications and standards compatible with present and emerging technology and approaches used in system design?

(d) Can contractual control be initiated through a single specification or standard?

(e) Is the specification tree complete?

(f) Is the precedence order clear?

(g) Are data users known?

(h) Are data needs of users known?

(i) Do the specifications and standards (with the contract) control data acquisition and delivery so that data users' needs are met?

(j) Are significant environmental effects controlled (temperature, shock and vibration, nuclear radiation, electromagnetic pulse, lightning)?

With the effectiveness criteria in mind, the general specifications and standards relating to the electronics interface with the electrical power system of ships and aircraft were reviewed. The same specifications were also reviewed for coverage of the signal-common interface between electronic equipments. Even though the review was far from complete, serious shortcomings in the general specifications and standards were found. No specifications unique to individual systems or equipments were reviewed.

5.3 FINDINGS USING SYSTEM APPROACH

Reviewing EM-Power specifications and standards from the system viewpoint revealed many serious problems with current Navy general specifications and standards. These problems included mismatch of conjoint specifications and standards, lack of coverage of important interface parameters, mismatch between the technology being used and the specification or standard, requirements in the specifications and standards forcing poor design practices, lack of technical guidance, lack of contractual control, and lack of adequate data requirements.

Several reasons were found for the above situation. In some cases, lack of good technical solutions makes writing adequate specifications and standards impossible. Lack of technical data makes defining realistic limits difficult. In other cases, Navy personnel with the technical knowledge have no responsibility, time, resources, or motivation for assuring that specifications and standards are technically adequate. The responsibility for assuring that conjoint specifications and standards match is unclear. Finally, there may be general agreement as to what should be done but nothing seems to happen. This is usually caused by a hierarchy of priorities and a lack of sufficient resources to work on anything but the top one or two priorities.

Specific findings of the system level review were as follows:

(a) Existing conjoint specifications and standards are mismatched on the common interfaces they control. An example of specification mismatch is shown by overlaying the voltage modulation limits of the specification that defines shipboard power, MIL-STD-1399 Sec 103, with the specification that ensures that electronic equipment is not susceptible to modulation of the power source, MIL-STD-461 CS01, as shown in figure 5-4. Note that there is a negative safety margin for 115-V equipment between the frequencies of 5 and 50 kHz. For 440-V systems, there is a continuous negative safety margin from 30 Hz to 50 kHz. This means that there is no guarantee that electronic equipment which has passed MIL-STD-461 modulation limits will operate with shipboard power systems that meet their modulation limits. Compatibility of interface specifications is a major task of the system approach to engineering. In this case, compatibility of specifications must still be achieved.

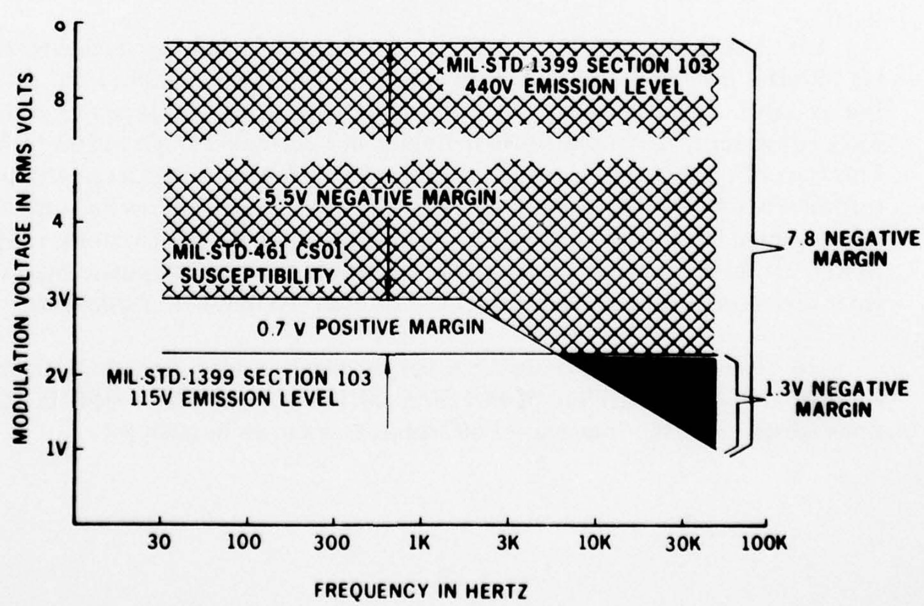

Figure 5-4. Electrical power interface specification mismatch

Another example of interface discrepancies occurs when the transient response of shipboard generators is examined. Their characteristic response frequency to load changes as shown in figure 5-5 is between 0.8 and 25 Hz for Type I shipboard power and between 2.5 and 25 Hz for Type II and III power. MIL-STD-461 does not test in the critical range, the lower limit of the CS01 test being 30 Hz. Modulations of 158V peak-to-peak are within power system specifications, and modulations of 80V peak-to-peak causing interaction problems have been observed on ships. Electronics are seldom tested for this range of modulation frequencies and voltages.

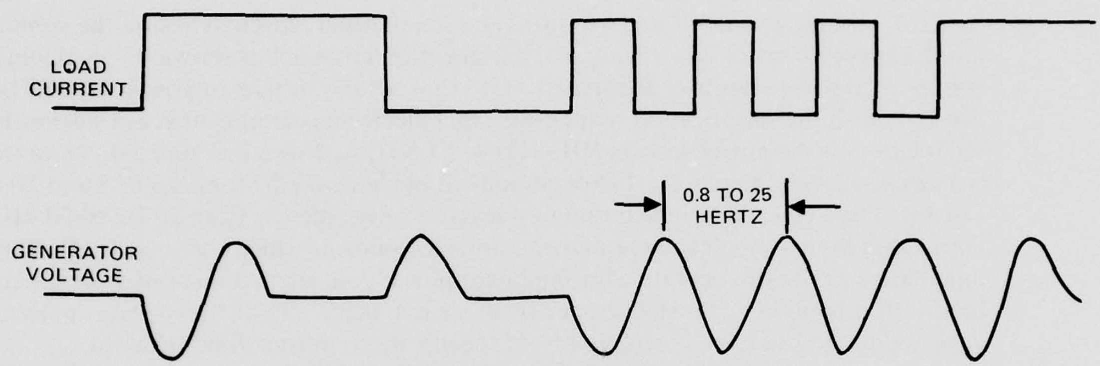

Figure 5-5. Generator response to load changes

(b) Existing specification requirements and the technology being used are incompatible. R&D is needed for technological approaches more compatible with system requirements. For example, six-pulse rectification, which is the most popular type of rectification in present Navy equipment, causes individual harmonic line currents as high as 20% (5th harmonic). This type of rectification is used extensively in the new switching regulator power supplies (off-line switching-mode regulators). New proposed specifications limit the 5th harmonic to 3%, as shown in figure 5-6. The filter needed to attenuate this harmonic (300 Hz for 60-Hz power) can be comparable in size to the electronic equipment's power supply. This is an obvious area needing system level tradeoffs and R&D to find better solutions.

(c) Existing specifications are generally silent on what to do with signal grounds. The exceptions are NAVSHIPS 0902-001-5000, MIL-I-983, and MIL-F-18870. All other specifications are silent on this important EMC subject, as shown in table 5-1.

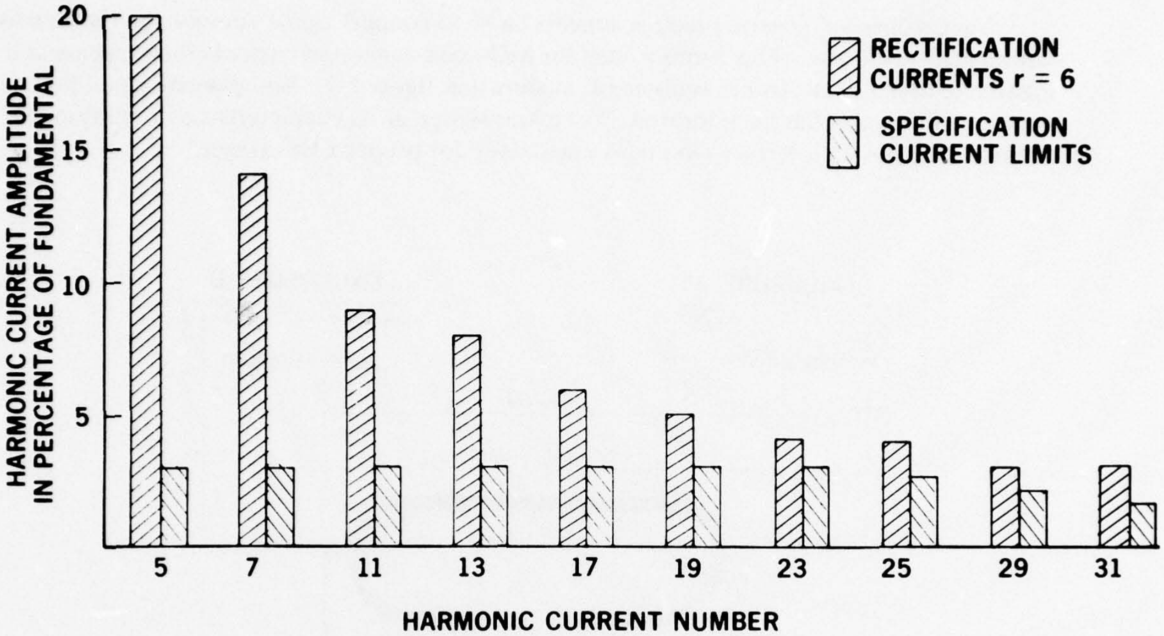

Figure 5-6. Harmonic currents caused by rectification

Table 5-1. Ground of Signal Common

SPECIFICATION	COMMENT
General Specification for Ships of the US Navy NAVSHIPS 0902-001-5000	Silent except for NTDS and ATE (section 400h)
Electronic Equipment, Ship and Shore MIL-E-16400	Silent
Shipboard Bonding, Grounding MIL-STD-454	Silent except for NTDS (section 5.1.1 and fig 9)
Standard requirements for electronic equipment MIL-STD-454	Silent
Shipboard Interior Equipment MIL-I-983	Amplifier power supplies grounded to hull at one point only. Hull shall not be used for signal common unless approved (section 3.8.6)
Fire Control Equipment MIL-F-18870	Single common ground connections routed to enclosure and then to ship structure (section 3.5.3.1)
Electronic Equipment, Missiles MIL-E-8189	Silent
Electronic Equipment, Ground MIL-E-4158	Silent
Electronic Equipment, Airborne MIL-E-5400	Silent
System EMC Requirements MIL-E-6051	Silent
Equipment EMI Requirements MIL-STD-461	Silent
Aerospace System Bonding MIL-B-5087	Silent

Navy shipboard general practice appears to be to connect signal common to the chassis within each enclosure. This forms a loop for hull-noise-generated currents that appears as a legitimate signal in electronic equipment, as shown in figure 5-7. No information on hull noise on Navy ships has been located. Yet a knowledge of its characteristics in relation to the noise margin on interface circuits is mandatory for proper EMC design.

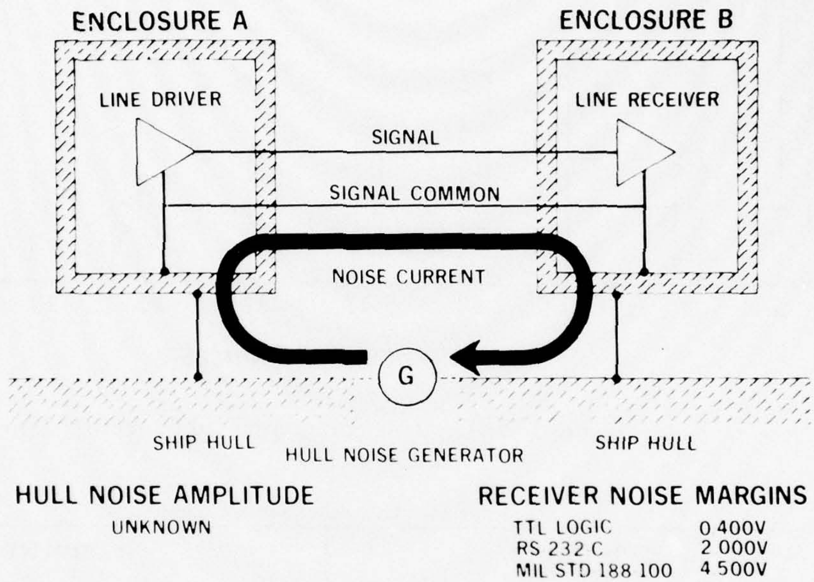

Figure 5-7. Signal common grounding: conducted interference

The NTDS grounding method has a similar need for describing the noise sources shown in figure 5-8. Common mode noise rejection is a related problem that requires better control.

(d) Many problems are apparent with a system-level orientation that remain hidden at the component- or equipment-level orientation. For example, the placement of the EMI filters (feed-through capacitors in figure 5-9) in the MIL-P-81279/9 power supplies is no problem unless the regulator is used as a negative power supply. There is still no problem until system integration. Then, somewhere in the system, signal ground and chassis ground are connected. When this occurs, the feed-through capacitors feed any noise on the input directly to the load, totally bypassing the regulator and its main filter. The result is unexplained glitches in the system. This type of sneak path is fairly common.

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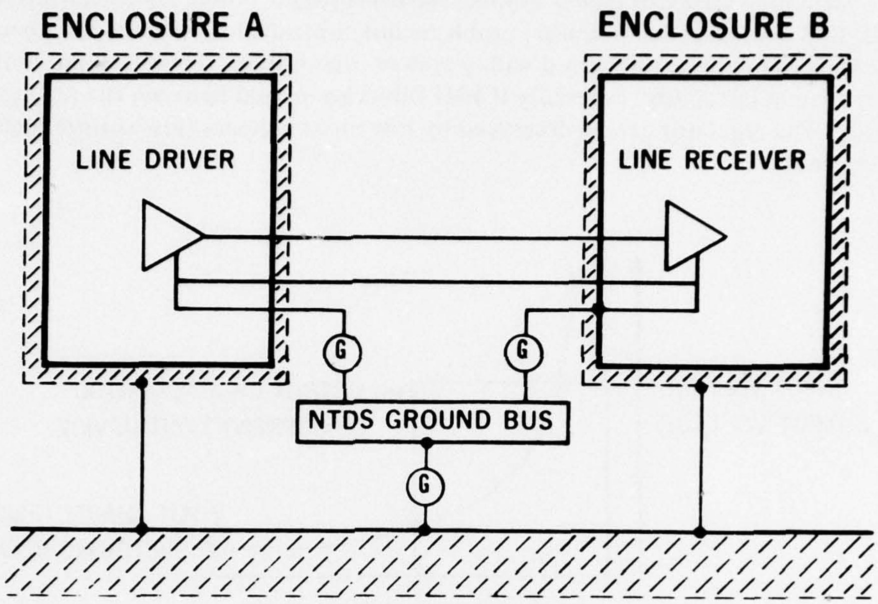


Figure 5-8. Signal common grounding: NTDS

• Methods of EMI control effective at regulator level can cause system problem.

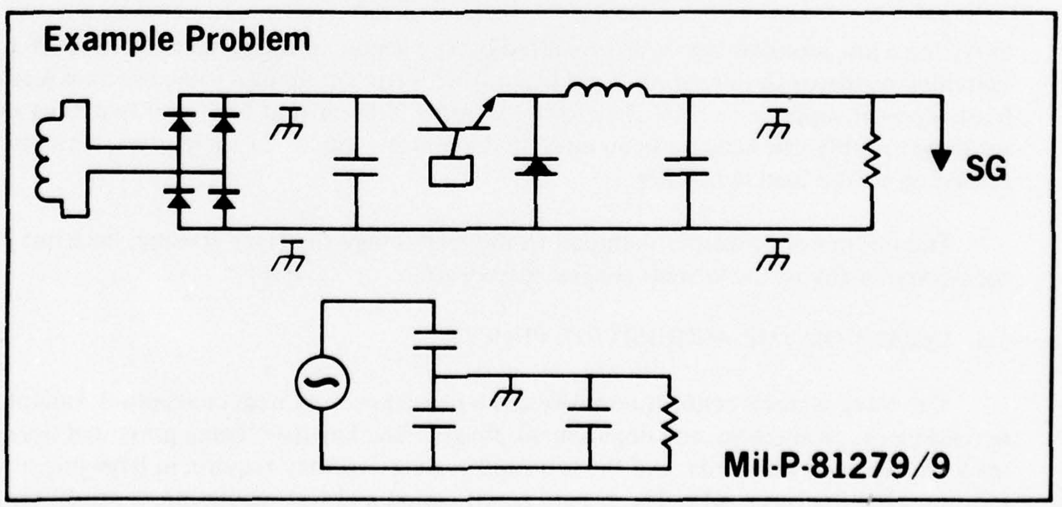
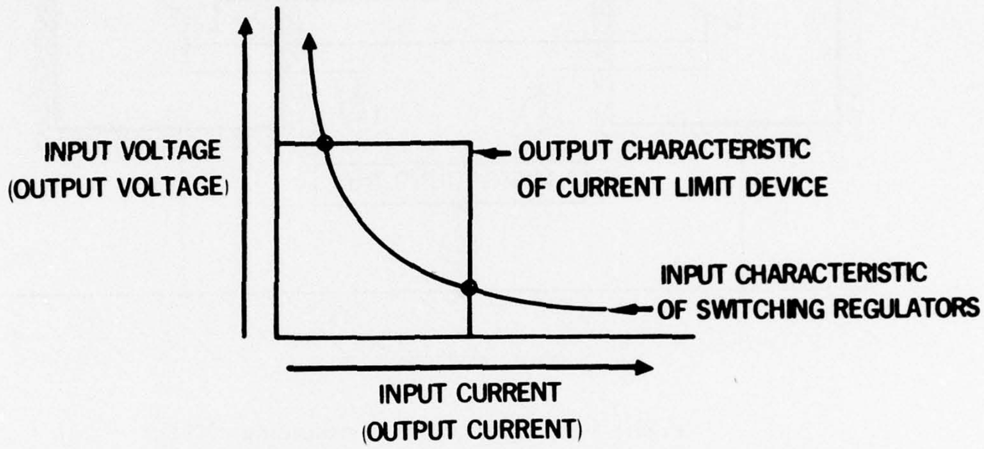


Figure 5-9. EMI problem

Switching regulator power supplies have a constant power input characteristic (figure 5-10) that causes several potential problems not controlled by specification because the problems can only be uncovered with a system orientation. Negative input impedance can cause system instability, especially if EMI filters are placed between the regulator and the source. The regulator can be destroyed by low input voltages (low voltage yields high input current).



- **Negative input resistance can cause power system instabilities**
- **Regulator can be destroyed by low input voltage**
- **Undesirable stable mode when operated from current-limited source**

Figure 5-10. Constant power input

Surviving a low input voltage is not required by any general military specification. If a switching regulator power supply is powered from a current-limited source such as a current-limited power supply or a solid-state load controller with current limit, the switching regulator power supply can hang up in an undesired operating mode. In some cases, it can never be turned on by the load controller.

These types of problems, common to the technology the Navy is using, have not been considered in any of the current general specifications or standards.

5.4 IMPACT ON THE ACQUISITION PROCESS

The Navy systems acquisition process is a phased process with conceptual, validation, development, production, and deployment phases. The key issue being presented here is that specifications and standards, and the tests and evaluations they require, in large measure determine what the Navy gets. The system specification and test requirements are an output of the validation phase in the acquisition process. Detailed specifications and test requirements, as well as test and evaluation results, are an output of the development phase. This

orientation of issues around specifications and standards was used in developing the entries in table 5-2. Table entries listed under the conceptual phase heading identify issues that have to be resolved before adequate systems specifications and test requirements can be written.

The specifications and standards are an abstraction of what is wanted. The reality of the system is in the hardware/software and operations procedures as delivered to and used by the Navy. Activities after the specification and test requirements are a form of reality testing and confidence building. Is the Navy getting what it asked for (through the contract specifications and standards) and does the system support the mission requirements? If the answer is no, reiteration through the phases is used to correct the situation.

The previous sections have shown that, as presently written, the general specifications and standards controlling EM-Power are only partially adequate for avoiding EM-Power problems. For air and ship programs it is indicated how the general specifications can be tailored by the detailed specifications so that the probability of avoiding EM-Power problems in the system is maximized.

AIR PROGRAMS. The general specification for airborne electronic equipment is MIL-E-5400. This specification covers the general requirements for airborne electronic equipment for operation primarily in piloted aircraft. The detail performance and test requirements for a particular equipment are specified in the detailed specification for that equipment. Appendix E provides the air program managers with the MIL-E-5400R EM-Power specification tree and a discussion, in flow diagram format, of how to tailor the detailed equipment/system specification to minimize EM-Power problems in the equipment/system.

SHIP PROGRAMS. The general specification for ships and its relationship to the various shipboard electronic specifications are discussed in appendix F. There is no flowgraph (equivalent to the one on MIL-E-5400) given as an aid to tailoring the detailed specifications; however, the EM-Power specification trees for MIL-E-16400 and MIL-F-18870 are provided. The flowgraph for MIL-E-5400 can be used as a guide for tailoring. Shipboard power for electronics should always be specified as 3-phase (reduces structure currents), 60-Hz (eliminates frequency changers), 440-V (eliminates step-down transformers), Type I (eliminates regulators) unless detailed trade studies show other power to be advantageous from the total system viewpoint.

5.5 ADEQUACY OF EM-POWER SPECIFICATIONS AND STANDARDS SUMMARY

The purpose of general specifications and standards is discussed and the conclusion is reached that they are an essential part of the contractual method by which the Navy assures it gets what it wants from a contractor. The EM-Power specifications are then reviewed from a system viewpoint and found to be incompatible with each other, with technology, and with Navy needs in many important aspects. The impact on the acquisition processes is discussed along with methods of tailoring detailed specifications to overcome the shortcomings of the general specifications until these shortcomings can be corrected.

TABLE 5-2. PHASES AND CONCERNS IN DEVELOPING SPECIFICATIONS AND STANDARDS.

CONCERN \ PHASE	CONCEPTUAL	VALIDATION	DEVELOPMENT	PRODUCTION	DEPLOYMENT
1. Loss of power	1. Determine mission impact of loss of power. 2. If needed, develop loss-of-power circumvention approach.	Complete, expand, and validate requirements and approaches made in conceptual phase. Incorporate into system specification and determine test requirements for all significant requirements. Highest priority is mission impact of loss of power and circumvention details if loss of power is unacceptable.	Monitor development to assure that all EM-Power concerns are reflected in the development, detailed specifications, and test requirements, and that the tests and evaluations performed effectively demonstrate compliance with requirements and provide data needed for system integration. Land-based test sites, system integration labs, TECHEVAL, and OPEVAL should be used to the greatest extent possible to demonstrate mission/system impact of loss of power and effects of electrical simulation of EM environments (EMP, lightning, signal ground noise, noise, common mode noise, modulation of power system, etc), so that corrective actions can be made before production and deployment.	Monitor production to assure no degradation in EM-Power concerns because of cost-reduction activities, engineering changes, quality assurance provisions, etc. Be alert to anomalies that could indicate EM-Power problems. These anomalies can include loss of digital data in memory or data transfer, malfunctions caused by glitches in factory power, failure of power supplies, circuits, and interface components because of electrical overstress, loss of data, or failures in power turn on/off, etc.	Continual evaluation of impact of new threats, operations, etc, on ability to perform mission; ie, is loss of power more likely or more critical in terms of a new threat or operational approach? Does a new requirement to work in an EMP environment make common mode noise rejection more critical? Does a new ECCM tactic change the pulse loading on the power system? Is this acceptable? During EMCON, will loss of power turn on transmitters?
2. Power	1. Determine type of input power. 2. Estimate amount of power. 3. Determine approach for pulse loads.				
3. Electrical protection	Determine whether standard protection philosophy is satisfactory. If not, develop philosophy.				
4. EMI	1. Define EM environment. 2. Estimate contribution of equipment/system to environment.				
5. Grounding	1. Develop signal-grounding philosophy. 2. Determine isolation requirements.				
6. Signal interfaces	Determine types of interfaces and required performance in each EM environment.				
7. Corona	If high-voltage system, determine impact of corona on life and EM environment. Determine approach.				
8. Data	Identify platform, type of power, amount of power, pulse loading, operation in EM environments, interface isolation, signal-grounding concept	1. System Specification. 2. Test Requirements.	1. System Description. 2. Test and Evaluation Results. 3. System integration data. 4. Corrective Actions	1. System integration data. 2. System and component failure data prior to and after acceptance testing.	1. Failure data. 2. Corrective Actions. 3. Lesson learned into acquisition cycle requirements, including specifications and standards.

6.0 FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The findings, conclusions, and recommendations of this report are included in the summary.

APPENDIX A

TESSAC EM-POWER TASK
PLATFORM/EQUIPMENT/SYSTEM/ENVIRONMENT
PRIORITIES

Preliminary Report

22 DEC 1976

REVISION C: 21 MAR 77

TESSAC EM-POWER TECHNOLOGY TASK TEAM

J Foutz	NELC, San Diego	Code 4340	Leader
PJ Johnson	NUSC, New London	Code 344	
JH Jentz	NAFI, Indianapolis	Code 835	
JD Segrest	NADC, Warminster	Code 6073	
JO Koegel	NATC, Patuxent River	Code SY60	
RJ Wilson	NRL, Wash. DC	Code 5210.3	
FL Henrickson	NAVSEC, Wash. DC	Code 6156D	
CR Young	DTNSRDC, Annapolis	Code 2781	

OTHER CONTRIBUTORS

J Henry	NELC, San Diego	Code 4340
E Kamm	NELC, San Diego	Code 4340
WJ Prysner	NUSC, New London	Code 41
HR Boroson	DTNSRDC, Annapolis	Code 278
G Danks	NATC, Patuxent River	Code SW60

TESSAC EM-Power Workshop Attendees
15, 16, 17 March 1977
Naval Research Laboratory Wash DC

JD Segrest	NADC, Warminster	Code 6073	
CR Young	DTNSRDC, Annapolis	Code 2781	
V Pugliese	DTNSRDC, Annapolis	Code 2781	
J Foutz	NOSC, San Diego	Code 743	Leader
J. Henry	NOSC, San Diego	Code 743	Asst. Leader
WE Welch	NOSC, San Diego	Code 441	Technical Editor
PJ Johnson	NUSC, New London	Code 344	
BJ Wilson	NRL, Wash DC	Code 5210.3	Host
JL Brooks	CEL, Point Hueneme	Code L62	
JR Hoffler	NAVSEC, Wash DC	Code 6156D	
G Danks	NATC, Patuxent River	Code SY66	
JH Jentz	NAFI, Indianapolis	Code 835	
R Plew	NWSC, Crane	Code 3026	
LC Martin	Lawrence Livermore Laboratory		Observer

REVISION	DATE	COMMENT
A	21 JAN 77	Incorporate team comments.
B	17 FEB 77	Add missing pages. Minor editing.
C	21 MAR 77	Incorporate EM-Power Workshop comments.

1.0 INTRODUCTION

One of the goals of the Tactical Electromagnetic System Study Action Council (TESSAC) technical team is to recommend specific actions that will ultimately improve the capability of Fleet aircraft and surface ships in performing their missions in various self induced and externally imposed electromagnetic environments. A preliminary task (ref a task 1.1.1) is to identify the platforms/equipments/systems and electromagnetic environments of concern to each technical team discipline and to rank them in order of priority. This report does this for the discipline of EM-Power. EM-Power is the TESSAC name used for the subset of electromagnetic compatibility (EMC), electromagnetic vulnerability (EMV), electromagnetic pulse (EMP), and safety disciplines related to the platform power system and the interface between the power systems and other electrical and electronic systems and equipments. Because the signal ground of electronic systems is usually the power supply secondary ground in electronic equipment, and because signal grounds on ships terminate on the ship hull, the EM-Power discipline also includes signal grounding topics.

Electric power is totally unique in that it is essential for all 15 mission areas of Fleet units defined in the Naval Combat Readiness Criteria (ref b). To list all of the Navy fleet units and their electrical/electronic equipment, none of which function without electrical power, would provide little useful information for TESSAC purposes. For this reason this report takes a more general approach where the functional properties of the electrical power system interface are ranked in priority of impact upon mission capabilities. The rationale for the ranking is discussed. Next the platform/systems/equipment priorities are determined by 1) how much the systems and equipments degrade the platform critical power characteristics, 2) how sensitive the systems and equipments are to degraded power, and 3) how sensitive mission capability is to these degraded systems and equipments. Finally EM environmental priorities are determined by the impact of the environment on platform critical power characteristics.

2.0 EM-POWER PRIORITIES

2.1 FUNCTIONAL PRIORITIES

The functional and nonfunctional properties of the electrical power interfaces are developed first in relationship to mission areas. These properties are then used to establish criteria for assigning priorities to specific platforms and equipments and to electromagnetic environments for the EM-Power discipline.

The properties of the electrical power interfaces in approximate order of priority are:

a) Discontinuity of power

b) Voltage and frequency variations (steady state and transient)

c) Load interactions

d) Voltage waveform distortion (ac power)

e) Hull current generator (ships)

These functions are further discussed.

2.1.1 Discontinuity of Power

Electrical power is essential to all fifteen mission areas of Fleet units (mission areas are listed in enclosure (3) of reference (b)). Thirteen of these mission areas involve either surface ships or aircraft or both. Without electrical power, these missions either cannot be performed at all or are severely hampered.

This is only part of the problem since restoration of electrical power does not necessarily immediately restore full mission capability. Reference (c) reports on the results of a survey of 37 Pacific Fleet ships asking for information about the frequency, criticality, and effect of momentary loss of power (3 to 30 seconds) upon ship mission capabilities. Many equipments suffer performance degradation for extensive periods of time, up to 20 hours to recover full operational capability. Table 1 summarizes the recovery times for the 65 equipments investigated. These equipments affect mission capabilities such as: loss of aircraft carrier ability to marshal aircraft, loss of precision landing control, aircraft identification, detection and tracking, fire-control coordination, missile firing, intercept control, ECM coordination, CIC data link, tactical displays, and navigational inputs to ship and aircraft. Loss of these mission capabilities has potentially serious effect on the ship safety and mission if the electrical power interruptions occur at a critical time. These interruptions occurred an average of 2.4 times a month for underway ships. Forty percent of the interruptions resulted in load equipment damage, degradation or excessive downtime.

The problems with power interruptions on aircraft can be similar and equally severe. Even though the power interruption is usually shorter on aircraft, typically less than 50 milliseconds on switchover, the aircraft requirement for small size and lightweight equipments puts a practical limitation on the energy storage capability of each aircraft equipment power supply.

TABLE A-1. RECOVERY TIME OF SHIPBOARD ELECTRONIC EQUIPMENT TO POWER INTERRUPTIONS (3 TO 30 SECONDS)

EQUIPMENT TYPE	TIME RANGE TO RETURN TO OPERATION (MINUTES)	TIME RANGE TO ACHIEVE FULL EQUIPMENT PERFORMANCE (MINUTES)
ECM	3	60
RADAR PPI	3	30
SONAR (FC)	5	5
SONAR	1-30	5-30
RADAR (TRAFFIC CONTROL)	3-15	60
NAVIGATION EQUIPMENT	45-240 (3/4-4 hrs)	60-1200 (1-20 hrs)
SEARCH RADAR	3-10	5-60
PROCESSING EQUIPMENT	1-180	180-300
RADIO COMMUNICATION EQUIPMENT	1-30	5-30

For these reasons, continuity of electrical power is considered the first functional priority in the EM-Power area for both ships and aircraft.

2.1.2 Voltage and Frequency Variations (Steady State and Transient)

The impact upon mission areas of deviations from voltage and frequency limits is highly dependent upon the sensitivity of electrical/electronic equipment to out of tolerance conditions. The degradation threshold is dependent upon parameters such as design margins, environment (eg, temperature), loading factors, usage, and manufacturing tolerances. Voltage and frequency tolerances that are grossly out of specification may activate protective circuits such as over/under voltage relays or over/under frequency relays and thereby have the same effect as loss of continuity of power. For these reasons, out-of-tolerance voltage and frequency characteristics of either a steady state or a transient nature are considered the second functional priority in the EM-Power area.

2.1.3 Load Interactions

A characteristic of the power interface is its capability to couple undesired signals (EMI) from one load to another and to the power systems through the equipment power lines. The effect of this EMI can range from loss of continuity of power or equipment damage to minor performance degradation of the susceptible equipment. Since loss of power is possible, load interactions are ranked third in priority.

2.1.4 Voltage Waveform Distortion (ac power)

Excessively distorted voltage waveforms can cause increased power losses in magnetic devices, reduce the torque of high-efficiency induction motors, excite undesirable vibration modes, cause some types of ac voltage and current meters to mis-indicate, affect regulator settings, degrade the accuracy of servo systems, and cause performance degradation of electronic equipment sensitive to voltage waveform distortion. The distorted waveform is also the driving potential for harmonic currents flowing in the hull. Since these phenomena normally result in a degradation of mission performance rather than loss of capability, voltage waveform distortion is ranked as the fourth functional priority in the EM-Power area.

2.1.5 Hull Current Generator

An undesired characteristic of the shipboard power system is to act as a generator for hull currents. As opposed to the grounded four-wire aircraft ac power system, the ship ac power system is an ungrounded three-wire system. Unbalance of capacitance to ground (often aggravated by EMI filters), unbalance of three-phase loads, and use of single-phase loads, all act to couple voltages into the low-impedance hull. Hull currents flow to neutralize these hull voltages. The presence of hull currents can affect the ship's ground detection system and degaussing system, and affect performance of equipment that is sensitive to current flow across the equipment enclosure.

In aircraft, the situation is different since the aircraft frame and skin are usually the neutral for the ac power system and the dc negative return. However, intentional use of the air frame as a current path may be a problem in an EMP and lightning environment and may offer other problems since newer aircraft use composite material panels in the skin.

2.2 PLATFORM/SYSTEM/EQUIPMENT PRIORITIES

The availability of electrical power with the proper characteristics is essential to accomplish the primary and secondary mission areas for all the surface ships and aircraft types listed in reference (b). The criteria used here to select the platform priorities for EM-Power are first, the presence of loads that degrade the platform electrical power characteristics (discussed in paragraph 2.2.1) and second, the equipment/system/mission sensitivity to degraded power (discussed in paragraph 2.2.2).

For ships, the worst of these conditions usually occurs on large combat ships.

For aircraft, the worst of these conditions usually occurs on aircraft using electrical actuators and motors (as opposed to hydraulic or other nonelectrical methods) and having critical electrical systems such as fly-by-wire systems or extensive data-processing equipment.

2.2.1 Load Degradation of the Power Interface

Most electrical power systems have little difficulty in maintaining proper output characteristics with linear static loads. Rectifier loads, pulsing loads, and motor starting loads are the problem loads.

Rectification of the ac power is a nonlinear process that distorts the power system voltage waveforms through the generation of harmonic currents. Almost all electronic loads rectify ac power and the larger electronics loads (radar, sonar, and ECM) are problem loads. These loads are also often large pulsing loads which cause modulation of the power system. When motors start, they demand a large inrush current, as does equipment having large capacitor banks which need charging. The surge currents drawn by these equipments produce voltage droops often followed by overshoot in the power system. This modulation of the power system can degrade sensitive loads.

2.2.2 Equipment/System/Mission Sensitivity to Electrical Power

Mission capability is more and more dependent upon electronics technology. Electronics technology tends toward the increasing use of digital processing and control techniques. And, in digital processing, the use of memory elements is increasing. As an example, system equipment interconnections are being designed as serial-data-transmission lines, which provide lower cabling weight and complexity and permit greater functional redundancy. The required parallel-to-serial conversion for serial data transmission requires memory elements, but digital systems with memory are very sensitive to transient power losses. For these systems, recovery software and hardware must be used to correct errors and to preserve and reconstruct memory. A paradox of this situation is that unless they are carefully designed, the most advanced platforms with the most advanced systems are those platforms most susceptible to loss of mission capability through degradation of power system characteristics.

2.2.3 Ship Platform Priorities

Based on the criteria discussed, the EM-Power priority leaders are ships combining large surging or pulsing loads with sensitive digital processing systems and ships having electrical automatic control systems. CVs and DLGs which combine search radars such as the

AN/SPS-48 with NTDS are examples of the former. The LHA, DD 963, and the PHM are examples of the latter. Excessive nonlinear loading of the power distribution to a point where harmonic voltage distortion becomes a problem is an EM-Power priority. This is likely on ships where electronic and other rectified loads are a major portion of the power system loads such as the more sophisticated combat ships.

2.2.4 Aircraft Platform Priorities

The EM-Power priority for aircraft are those having electrical actuators and/or pulsing loads combined with digital processing equipment and those having digital controls or electronic control systems. Examples of the former would be aircraft like the E-2C, S-3A, and F-14 which all have sophisticated digital processing equipment as well as pulsing radars and electrical control surface actuators. Examples of the latter are fly-by-wire systems which use low-level signals to actuate control surface motors such as the F-16 and F-18.

2.3 ENVIRONMENTAL PRIORITIES

The severest EM environment for the electrical power system is one that risks loss of continuity of power. Intuitively this would seem most likely to occur during an electromagnetic pulse (EMP). The input power lines to electronic equipment are known input ports for potentially damaging EMP effects. Pulses in the power system could affect electronic equipment so that it would appear as a transient or permanent short circuit to the power system, causing protective circuits to activate. This depends on the extent to which EMP effects get into the power system, which is unknown (by the EM-Power team) at this time. The potential effect of the EMP environment upon aircraft electrical systems has been explicitly recognized in the Operational Requirement (OR) (reference (d)) for the Advanced Aircraft Electrical System (AAES). EMI/EMP protection is listed first in the capabilities required in this OR.

Other severe EM environments for the electrical power system are those that place the greatest dynamic loading upon the power system. This would occur during combat conditions where radars, sonars, missile launchers, guns, ECM, aircraft, and ammunition elevators are all functioning. This is also the environment in which susceptible equipment must operate with minimum degradation. Combat is also the environment where non-EM threats (battle damage) may also cause loss of continuity of power.

2.4 SUMMARY OF PRIORITIES

The maximum impact upon mission areas in EM-Power occurs when continuity of power is lost. This is most likely to occur during combat operations in which battle damage occurs and possibly when an electromagnetic pulse (EMP) occurs. The effect on mission capability due to loss of continuity of power may be substantial.

Situations that place the greatest dynamic load on the power system are the next priority. Again, this usually occurs during combat conditions and has the greatest effect on mission areas when the effects of the dynamic loading of the power system cause degradation of susceptible equipment. The major dynamic loads are large motors, electrical actuators, radars, sonars, and pulsed high-power ECM and lasers. There is no generic way to define susceptible equipment but equipments using digital data processing and automatic

controls are of special interest because of their increasing use and their impact on mission capability when they malfunction.

REFERENCES

(a) Statement of Work for TESSAC Technical Teams, 28 Sep 76

(b) OPNAVINST 3501.2D, OP-643C, 24 Jul 1974
From: Chief of Naval Operations, Subj: Naval Combat Readiness Criteria

(c) Chief of Naval Development, Navy Technology Projections, Part III, Advanced System Concepts, Improved Continuity of Shipboard Power, 1 October 1971

(d) OR-WSL04, Operational Requirement (OR) Advanced Aircraft Electrical Systems (AAES), 8 Jul 1975

APPENDIX B: ELECTROMAGNETIC ENVIRONMENTAL DESIGN PROCEDURE

The Statement of Work for TESSAC technical team leaders (A-2) used a flow diagram of the electromagnetic environmental design procedure (figure B-1) as a methodology for determining the state of the technology and the technical capabilities of the Navy. The EM-Power discipline found this methodology quite useful in locating and collecting the needed data.

During visits to Navy facilities and at the EM-Power Workshop, questions based upon the design procedure were asked. Interviewees were asked what tools and techniques they used to select system components. Example questions were: How do you determine the kilowatt rating of the ship-service turbine generators for the conceptual design of a ship, or how do you determine the attenuation needed for an EMI filter? They were also asked what tools and techniques they used to arrange system components. Example questions were: How do you determine cable spacing or how do you do circuit design? Other questions asked for analytical and measurement tools and techniques. The tools and techniques compiled by this process are listed in table B-1. Each page of the table is a description of a design procedure used to select, arrange, analyze, or measure components in a system, subsystem, or circuit.

The tool or technique used in the Navy EM-Power electromagnetic design process most frequently listed by the respondents was the "engineering judgment" of the engineer assigned to the task. This is described in general terms for EM-Power in the first design procedure.

In this collection of procedures, no attempt was made to describe common, widespread procedures used by many facilities, such as the ability to make measurements as cited in MIL-STD-461. In addition, since any laboratory can perform any task given sufficient time and funding, no capability was included in the table unless that capability was being used for EM-Power purposes with equipment and trained personnel presently available.

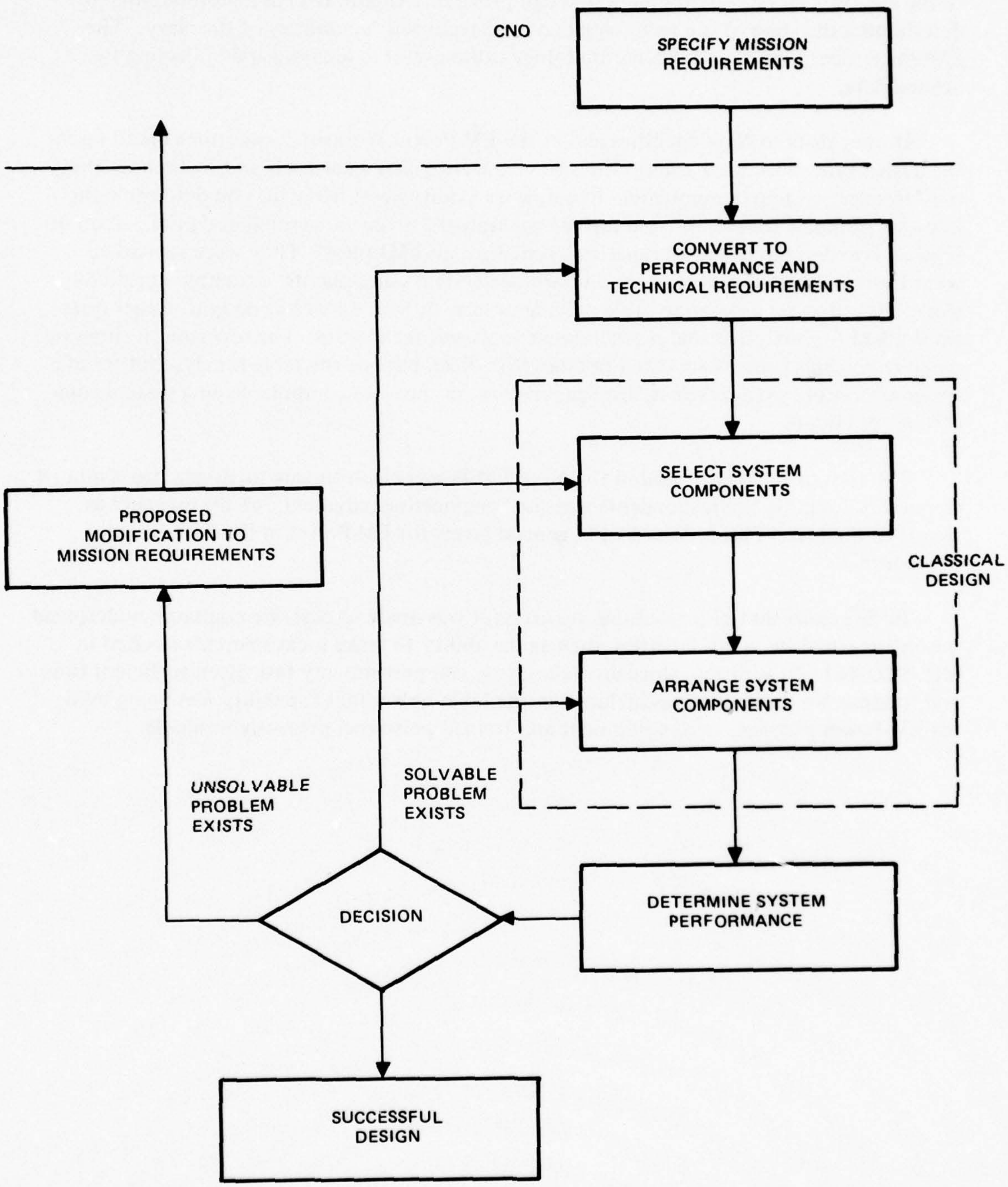


Figure B-1. Electromagnetic environment design procedure.

TABLE B-1. ELECTROMAGNETIC ENVIRONMENTAL DESIGN PROCEDURES.

Electromagnetic Environmental Design Procedure 1

NAME: Engineering Judgment.

DESIGN PROCEDURE: Select, Arrange, Analyze, and Measure.

METHOD: Personal judgment of engineer doing work, as modified by those having supervisory or approval authority over his work.

DESCRIPTION: Engineer assigned the task decides or is given an approach within his capabilities and resources and proceeds in doing the job.

INPUT: Professional training, experience, observations, calculating tools, textbooks, handbooks, specifications, standards, rules and regulations, opportunity to observe or measure, measurement tools.

OUTPUT: Selected components, arrangement of components, analysis of performance, measurement of performance.

STATUS: Operational. Design in the EM-Power field relies heavily on the experience of senior personnel and on measurement and test to validate the design. The lack of state-of-the-art analytical capability, the lack of an adequate documented corporate memory, a very limited flow of young engineers into the Navy EM-Power field, and the growing sophistication of the field indicate there may be a serious loss of capability when present experienced personnel are lost through attrition.

COMMENTS: None.

REFERENCES: None.

FURTHER INFORMATION: J Foutz, Code 9234
NOSC, San Diego, CA
AV 933-2752.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 2

NAME: Cable Spacing.

DESIGN PROCEDURE: Arrange; also, aid in selection and analysis.

METHOD: Handbook tables.

DESCRIPTION: Identifies the cable separation and cable shielding requirements in power/electronic signal distribution of submarines. The procedure can be used for other platforms.

INPUT: Susceptor and radiator category, frequency range of signals on cable, amplitude of signals, cable types, design performance sensitivity of susceptor, and cable spacing restriction (maximum cable spacing permitted in installation).

OUTPUT: Using the input information, the radiator and susceptor categories and group numbers are established from tables. The susceptor and radiator group numbers are coordinates on a table where the intersection yields the minimum cable spacing (inches) without additional shielding. If additional shielding is required, the effectiveness in dB is determined from the lowest frequency in the passband of the susceptor. A new susceptor group number corresponding to the susceptor cable with shielding is assigned. If the new minimum spacing is less than the spacing restriction, the cabling will present no system degradation with the installation.

STATUS: Operational. The need for this type of analysis on platforms other than submarines has been realized and NUSC was requested to change the title of the handbook to reflect ships rather than submarines. This was recently done.

COMMENTS: This capability is becoming more important because modern detectors and receiving circuits are being designed with increased sensitivity and lower front-end noise characteristics, thereby making them sensitive to performance degradation by electromagnetic interference. This cable analysis was used in the TRIDENT submarine program development and significantly reduced the weight and cost because shielding was eliminated in those cases where the analysis proved it unnecessary.

REFERENCE: NAVSHIPS 0967-LP-283-5010, Handbook of Shipboard Electromagnetic Shielding Practice, Section 6, Prepared by Naval Underwater Systems Center, New London, for Naval Ship Engineering Center, 1 March 1968, Change 5, 1 December 1977.

FURTHER INFORMATION: PJ Johnson, Code 344
Naval Underwater Systems Center
Newport, RI 02840
AV 636-2626.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 3

NAME: Harmonic Voltage Distortion.

DESIGN PROCEDURE: Analyze.

METHOD: Computer modeling (Fortran).

DESCRIPTION: A computer program determines the harmonic voltage distortion at various points in the ac electrical power distribution system caused by loads containing rectifier circuits (virtually all electronic and dc loads). Accurate through 13th harmonic.

INPUT: Topology of the power distribution system and loads, parameter values for generator (pure inductor), cable (pure inductor), and filter models (inductor-capacitor networks), kW rating of each load from power analysis or other data source. Any unique information or harmonic current amplitude distribution if known. Program assumes 6-pulse rectification with inductive input filter on load side of rectifier if not modified by unique information.

OUTPUT: Individual harmonic voltages at all nodes of the power distribution system. Distortion for various slopes of fall-off current amplitudes is output; (ie, 6 dB/octave, 9 dB/octave, 12 dB/octave).

STATUS: Operational. Model fully validated by comparing to actual measurements taken on submarine land-based test site and actual submarine power systems. Program consists of approximately 100 FORTRAN statements, NUSC, New London, has extensive data base on all types of Navy cables used in power distribution systems (presently available as computer printout) that can be used to obtain cable parameters needed in model. Parameter data are available for some submarine generators at NUSC. DTNSRDC has data for some surface ship generators. CEL has data for some shore generators. Generator manufacturers are also a source for generator inductive output impedance data.

COMMENTS: None.

REFERENCE: NUSC Technical Memorandum 344-477-76, Prediction of Total Harmonic Distortion on Shipboard Power Systems

FURTHER INFORMATION: G Majewski, Code 344
NUSC, New London, CT
AV 636-2629.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 4

NAME: Harmonic Voltage Distortions – Higher Harmonics.

DESIGN PROCEDURE: Analyze.

METHOD: Computer modeling.

DESCRIPTION: Extends existing computer modeling program for determining harmonic voltage distortion at various points in the ac electrical power distribution to a program that analyzes the harmonic distortion at frequencies greater than the 13th harmonic. The analysis takes into account the number of loads applied to predict the amount of harmonic phase cancellation that can be expected.

INPUT: To be determined.

OUTPUT: To be determined.

STATUS: Under development. Being developed by the University of Pennsylvania and NUSC. A rough draft report is complete on the concept and approach with theory and test data. Plans are to incorporate the results into an existing program after the approach is reviewed and validated.

COMMENTS: None.

REFERENCE: Report in progress (3/11/77)

FURTHER INFORMATION: G Majewski, Code 344
NUSC, New London, CT
AV 636-2629.

Dr Ralph Showers
University of Pennsylvania, Moore School of Engineering
(215) 243-8123.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 5

NAME: Structure Current Measurement-Cable Probe.

DESIGN PROCEDURE: Measure.

METHOD: Measurement using current probe.

DESCRIPTION: Current will flow in the grounding structure (ship hull) if the feed-through capacitors in two equipments are not balanced. This current can be measured by placing a current probe around the cable carrying power between the equipments and measuring the current unbalance in the cable. This is illustrated in figure B-2a for two equipments using single-phase power. Figure B-2b is the equivalent circuit that can be used to calculate the current flowing in the hull between the enclosures. This current can be measured with a current probe around the power cables between the two equipments, since the current on the hull is equal to the unbalance of current in the cable. A 10-percent unbalance of one capacitor will cause about 2.3% of the current flowing in a feed-through capacitor to flow through the hull.

INPUT: Not applicable.

OUTPUT: Measurement of unbalanced power cable current equal to hull current.

STATUS: Operational.

COMMENTS: None.

REFERENCE: NUSC ltr ser 7344-189, Procedure for Measurement of Structure or Common Mode Noise, Enclosure 3, 20 May 1977

FURTHER INFORMATION: PJ Johnson, Code 343
NUSC, New London, CT
AV 636-2626.

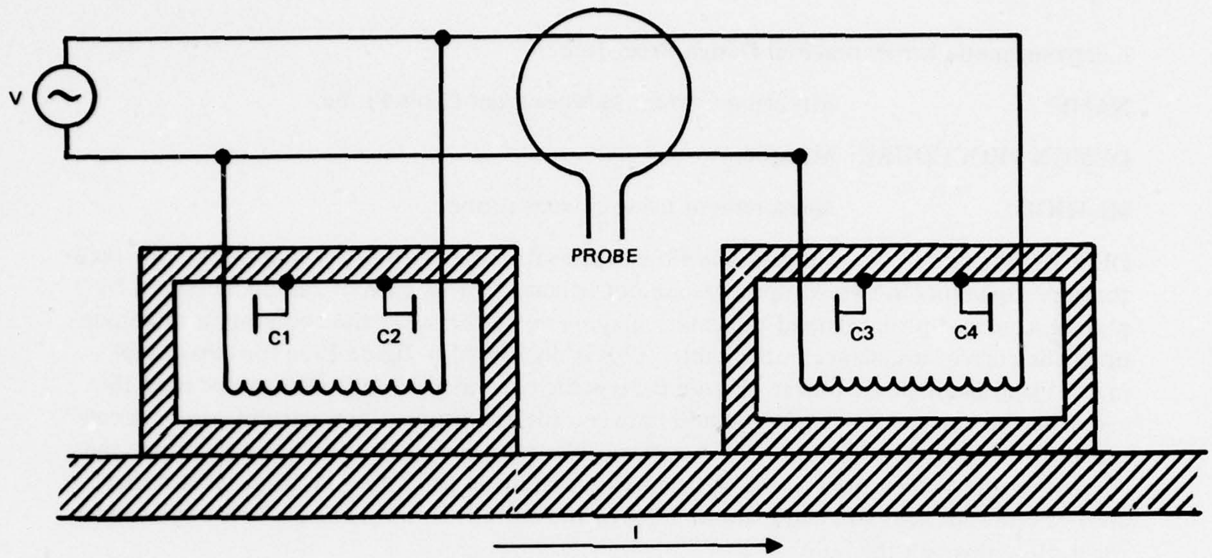


Figure B-2a. Equipment geometry.

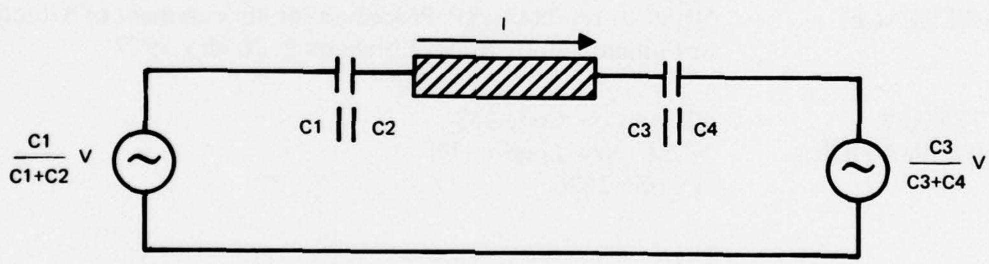


Figure B-2b. Equivalent circuit.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 6

NAME: Structure Current Measurement – Coil Probe.

DESIGN PROCEDURE: Measure.

METHOD: Measurement using Helmholtz coil and current probe.

DESCRIPTION: An electromagnetic pulse (EMP) induces currents in all metal structures exposed to the pulse. Current flowing in the structure creates an H-field that can be sensed by a Helmholtz coil adjacent and perpendicular to the surface. A current probe around the coil induces a current proportional to the current flowing in the structure.

INPUT: Not applicable.

OUTPUT: Measurement of current flowing in exterior structure of an aircraft or ship resulting from an EMP.

STATUS: Operational.

COMMENTS: Adaptable to other structure current measurements besides EMP effects.

REFERENCES: AFWL EMP Measurement 1-1, Air Force Weapons Laboratory Electromagnetic Pulse Sensor Handbook, Jun 1971.

FURTHER INFORMATION: RJ Haislmaier, Code WA51
NSWC, White Oak, MD
AV 290-1743.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 7

NAME: Ship Power Requirements-Conceptual.

DESIGN PROCEDURE: Select.

METHOD: Computer modeling.

DESCRIPTION: Estimates the size of the ship's electric plant prior to the availability of any information on the power consuming equipment. This estimate is computed by entering such parameters as the ship's length, width, tonnage, number of people berthed, and mission. The calculation is made from a single equation in a FORTRAN program for ship design consisting of 10 to 20k FORTRAN statements.

INPUT: Ship's length, width, tonnage, number of people berthed, mission, etc.

OUTPUT: Estimated number of kilowatts required to power ship's electrical system.

STATUS: Operational.

COMMENTS: Results have been as close as 3% of the measured load.

REFERENCES: Ship Design Synthesis Models – Destroyer Model DD67

FURTHER INFORMATION: A Fuller, Code 6144
NAVSEC, Wash, DC
AV 222-8160

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 8

NAME: Aircraft Power Requirements – Conceptual.

DESIGN PROCEDURE: Analyze.

METHOD: Load analysis.

DESCRIPTION: Estimates the size of the aircraft generators required on new aircraft. A preliminary load analysis is made based on background data, core avionics, estimated mission avionics, weapons systems, and growth potential. Refinements are made as actual load data become available.

INPUT: See description.

OUTPUT: Size of electrical power plant in kW.

STATUS: Operational

COMMENTS: None.

REFERENCES: Military Specification MIL-E-7016F (ASG), Electrical Load and Power Source Capacity, Aircraft, Analysis of, 20 Jul 76.

FURTHER INFORMATION: J Segrest, Code 6073
NADC, Warminster, PA
AV 441-2354.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 9

NAME: Ship Power Requirements – Load Power Analysis.

DESIGN PROCEDURE: Select.

METHOD: Computer modeling.

DESCRIPTION: This Fortran program is used to perform a power analysis of a ship's electrical system from a list of power consuming equipment and is used to determine the size and number of electric generators required. It is also used by the shipbuilder as a basis for developing the final list of a ship's power consuming equipment.

INPUT: Power consuming equipment parameters are entered into the computer manually or by computer extraction from a library file on power consuming equipment. The data entered consist of equipment call number, name, horsepower, and kilowatts. Each equipment input is listed by load categories (auxiliary machinery, hotel, propulsion auxiliary, steering, etc) up to a maximum of six categories. Each input must also be labeled with the power loading for various operating conditions (anchor, cruising, battle, etc).

OUTPUT: The program performs all the data manipulation, calculation and formatting from a list of power consuming equipment for the analysis of the ship's electric plant. The processing consists of multiplying the quantity of equipment by the kilowatts per equipment to obtain the connected load. This, in turn, is multiplied by each ship's functional load factor to obtain the ship's functional loads. Output data are formatted to print equipment title, category, and loads. An option can list power consuming equipment and power category numbers grouped according to their power categories. A summary page lists the total power required for all load categories with a 30% growth factor allowance. The growth factor is not applied to the propulsion and steering categories because future power demand is not anticipated.

STATUS: Operational. This work was authored and has been used since 1966.

COMMENTS: None.

REFERENCES: The procedure is documented in NAVSHIPS 0900-006-5150, Ship Design Computer Program, Ship's Electric Power Analysis and List of Power-Consuming Equipment.

FURTHER INFORMATION: FL Henrickson, Code 6156D
NAVSEC, Wash DC
AV 222-6062.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 10

NAME: Aircraft Power Requirements – Load Power Analysis.

DESIGN PROCEDURE: Analyze.

METHOD: Specification.

DESCRIPTION: This analysis identifies individually the real and reactive power required for each load and computes the total power requirement for all aircraft operating conditions in order to assure that the primary, secondary, and emergency electrical power systems have adequate capacity.

INPUT: Input data consist of individual equipment loads and load usage versus flight mode.

OUTPUT: Total power requirement versus flight mode.

STATUS: Operational. This procedure is used on all Navy aircraft.

COMMENTS: All airframe contractors have this capability, either by manual or computer-aided compilation. The electrical load analysis per MIL-E-7016F is required for all Navy aircraft.

REFERENCE: Department of the Navy Military Specification MIL-E-7016F(ASG), Electrical Load and Power Source Capacity, Aircraft, Analysis of, 20 July 1976

FURTHER INFORMATION: WL File, Code SY60
NATC, Patuxent River, MD
AV 356-4161.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 11

NAME: Fleet Maintenance Data Bank (MDCS, 3-M).

DESIGN PROCEDURE: Data Bank.

METHOD: Data acquisition and retrieval system.

DESCRIPTION: Establishes a historical data base on in-service equipments with regard to maintenance and logistic support requirements.

INPUT: Reports filled out by the Fleet maintenance technicians responsible for the equipment reported on; these reports include completed corrective maintenance, failed parts reports, deferred preventive and corrective maintenance, and field change/alteration status. The reports include, as applicable, the unit reporting (ship, aircraft squadron), the equipment reported on, identifying numbers (serials, identification codes, etc), man-hours expended, parts costs, various codes describing as-discovered information, equipment status, cause of action, action taken, and a narrative of the maintenance action.

OUTPUT: A wide variety of standard output reports that array the information by equipment, ship, or ship type is available. Most maintenance and logistics parameters can be obtained directly or easily computed from MDCS reports. Trends and status of equipment support can be ascertained. Man-hour expenditures and support costs are readily accessible.

STATUS: Operational.

COMMENTS: MDCS data are useful in monitoring logistic support status, computing actual life-cycle costs, and identifying chronic design deficiencies and high-failure-rate components. The analysis of existing equipments is often an essential step in determining design-to-cost support parameters for new equipments.

REFERENCES: 1) OPNAV 43P2, Maintenance & Material Management (3-M) Manual, OPNAV 433, 10 Oct 1969 (frequent changes)

2) Catalog of 3-M Products, MSO Instruction 4790.1A (Air) and 4790.2 (Ship), Fleet Material Support Office, Mechanicsburg, PA.

FURTHER INFORMATION: Maintenance Support Office Department
Fleet Material Support Office
Mechanicsburg, PA 17055
AV 277-2043 (Ship)
AV 277-2031 or 2669 (Air).

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 12

NAME: Cable Parameter Data Base.

DESIGN PROCEDURE: Data Bank.

METHOD: Tables.

DESCRIPTION: This tool is a data base describing the electrical characteristics of cable types used in submarines. The same cables are used in surface ships.

INPUT: Cable designation number (any cable listed in MIL-C-915 or MIL-C-17).

OUTPUT: Inductance, capacitance, current carrying capacity, and radiation characteristics.

STATUS: Operational. This data base is actively used as an input to the TRIDENT EMC prediction models for determining low-frequency cable separation requirements and harmonic voltage distortion content. The cable parameters are presently available as a computer printout.

COMMENTS: Cable models were validated by empirical measurement.

REFERENCES: NUSC ltr ser 7344-38, Standard Navy Twisted Wire Cable Data, Enclosure 1, 28 June 1977

FURTHER INFORMATION: G. Majewski, Code 344
NUSC, New London, CT
AV 636-2629.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 13

NAME: Load/Power Source Interactions.

DESIGN PROCEDURE: Analyze.

METHOD: Computer simulation (analog).

DESCRIPTION: An analog computer simulator is used to model the power generator responses to repetitive pulse loads up to 3 kHz. Large pulsing loads can cause excessive power line ripple or regulator instability in dc generator systems. This simulation will establish performance limits of the generator system.

INPUT: Generator system analog and power processor (load) analog.

OUTPUT: System voltage stability as a function of load pulse amplitude.

STATUS: Operational. This analysis is being applied in aircraft generator development programs by Garrett Corporation. The capability is not available in a Navy facility.

COMMENTS: None.

REFERENCES: None.

FURTHER INFORMATION: RH Ireland or J Segrest, Code 6073
NADC, Warminster, PA
AV 441-2354.

F Echolds
Garrett Corporation, Torrance, CA
(213) 323-9500 X3203.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 14

NAME:	Mobile Test Van-Aircraft.
DESIGN PROCEDURE:	Measure.
METHOD:	Measurement.

DESCRIPTION: A van especially configured with a full complement of analog and digital instrumentation to measure steady-state and transient electrical power parameters on an operating aircraft on the ground.

INPUT:	Not applicable.
OUTPUT:	Test data.
STATUS:	Operational. Currently is used at NATC.

COMMENTS: Mobile laboratory has facilities to communicate with aircraft pilot to coordinate measurements with aircraft operating conditions.

REFERENCE:	None.
FURTHER INFORMATION:	GR Danks, Code SY60 NATC, Patuxent River, MD AV 356-4701.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 15

NAME:	In-Flight Data Acquisition System.
DESIGN PROCEDURE:	Measure.
METHOD:	Measurement.

DESCRIPTION: Complete airborne instrumentation system adaptable to various types of aircraft which has capability of in-flight recording of steady-state parameters related to the aircraft electrical system.

INPUT:	Not applicable.
OUTPUT:	Test data.
STATUS:	Operational. Currently in use at NATC.

COMMENTS: Data can be recorded for later reduction or can be telemetered and reduced on a real-time basis. The system is adaptable for measurement of transient parameters.

REFERENCE:	Not applicable.
FURTHER INFORMATION:	GR Danks, Code SY60 NATC, Patuxent River, MD AV 356-4701.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 16

NAME: Power Transient Synthesizer.

DESIGN PROCEDURE: Measure.

METHOD: Susceptibility test equipment.

DESCRIPTION: The power transient synthesizer was developed by the Civil Engineering Laboratory as a source of power with controlled output parameters for susceptibility testing and calibration of equipment. It simulates fluctuations and disturbances which occur in utility alternating current power supply systems and in poorly regulated direct current power sources. The synthesizer is fundamentally a solid-state power supply providing (1) ac power at 15 kVA, 120/208 volts, 3 phase, or 7.5 kVA, 120 volts, single phase, at base frequencies of 50 or 60 hertz; and (2) dc power at 1 kW, 0-264 volts. It supplies power with overvoltages, undervoltages, momentary power outages, pulse voltages superimposed on the fundamental sine wave or dc output, frequency deviations about the fundamental frequency (50 to 60 hertz), and high frequencies (400 to 10000 hertz) in magnitudes up to 75 volts root mean square (rms) superimposed on any selected phase of ac power or the dc power output. Phase control circuitry is also provided to permit asynchronous operation of the synthesizer for testing electrical equipment, such as solid-state switches, at selected phase differences with respect to the normal ac power source.

INPUT: Manually selected control settings for voltage, excursions, and timing.

OUTPUT: Equipment susceptibility data.

STATUS: Operational. Available with operator upon request.

COMMENTS: Very useful for susceptibility testing of individual equipment.

REFERENCES: Naval Research Reviews, High Quality Electric Power, by Evo Giorgi, April 1975.

FURTHER INFORMATION: J Brooks, Code L62
CEL, Point Hueneme, CA
AV 360-4660.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 17

NAME:	Power Transient Data Acquisition Monitor.
DESIGN PROCEDURE:	Measure.
METHOD:	Measurement hardware and data storage and retrieval.

DESCRIPTION: The power transient data acquisition monitor is designed to record and store randomly occurring power-line disturbances in real time. The monitor contains a magnetic drum/magnetic tape recording system. The monitored waveforms are continuously recorded and erased from the rotating magnetic drum. When a transient is sensed, a signal is provided to initiate the quick-start magnetic tape, whereupon data on all 12 channels are transcribed onto tape. This technique enables the recording of all waveforms, pretransient, transient, and posttransient, associated with power disturbances. It also shortens data processing time because the stored information is limited to power disturbance data only. Transient voltage and current waveforms may be recorded.

OUTPUT:	Hardcopy analog transient data with time information.
STATUS:	Operational. Available with operator upon request.

COMMENT: This tool is very useful when it is necessary to characterize the power disturbances completely.

REFERENCES: Naval Research Reviews, High Quality Electric Power, by Evo Giorgi, April 1975.

FURTHER INFORMATION: J Brooks, Code L62
CEL, Point Hueneme, CA
AV 360-4660.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 18

NAME: Power Line Disturbance Monitor.

DESIGN PROCEDURE: Measure.

METHOD: Power-line transients are measured and counted and the direction of propagation is determined.

DESCRIPTION: A power-line disturbance monitor has been developed to identify the power input anomalies at critical facilities. The instrument can identify undervoltage, overvoltage, frequency deviation, and impulse voltages. Also provided are controls for selecting the various thresholds. A printer, which incorporates a Julian clock and records the day and time of each disturbance, and an attachment for determining the direction of propagation for impulse type voltages are also provided.

INPUT: Not applicable.

OUTPUT: Hardcopy record of power-line occurrences by type and time.

STATUS: Operational. DoD technology transfer to industry is accomplished. Monitor is now being commercially produced.

COMMENTS: Very useful instrument for identifying power line problems and assigning responsibility for solving the problem.

REFERENCES: CEL Technical Note, N-1388, Prototype Powerline Transient Source and Direction of Propagation Detector, by MN Smith and KT Huang, May 1975.

FURTHER INFORMATION: J Brooks, Code L62
CEL, Point Hueneme, CA
AV 360-4660.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 19

NAME: CASREPT Reporting System.

DESIGN PROCEDURE: Data Bank.

DESCRIPTION: The casualty report (CASREPT) provides a timely method for reporting equipment failures and the effect of these failures on the capabilities of the reporting unit. This allows the support community to react most rapidly to the highest-priority requirements to sustain the Fleet at a high readiness level.

INPUT: CASREPTs are submitted in message form. Each report contains a description of the problem, the mission capabilities affected, a listing of support requirements (technical assistance, spare parts) needed, and an estimated time to correct.

OUTPUT: Data bank analysis products are available by command, ship type, hull number, and equipment. The standard products include material condition index reports, mission essential material readiness and condition index reports, parts data usage reports, and weekly summary reports. The failures that have the greatest impact on Fleet readiness can be identified and appropriate maintenance and logistics parameters computed.

STATUS: Operational.

COMMENTS: The data from CASREPTs are very similar to those available from the MDCS (3-M) system. The CASREPT system is essentially real time, as opposed to the 3 to 6 month lag of MDCS. The CASREPT system contains only priority failures, so it contains only about 10% of the data obtainable from MDCS. But CASREPTs are valuable in assessing the criticality of an equipment to ship missions and in designing maintenance and support concepts for replacement equipments. Cost analysis using CASREPT data should be conducted only in conjunction with MDCS data.

REFERENCES: 1) NWIP-10-1(D) (Naval Warfare Information Publication)

2) Consolidated CASREPT Reporting System Reports Catalog, Navy Fleet Material Support Office, Mechanicsburg, PA, 5th edition, October 1974.

FURTHER INFORMATION: Fleet Material Support Office
Mechanicsburg, PA 17055
AV 277-2312, 2848.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 20

NAME: Hybrid Computer.

DESIGN PROCEDURE: Analyze.

METHOD: Computer simulation.

DESCRIPTION: A hybrid computer is used as a tool for the simulation of a ship's turbine generator and uninterruptible power supplies. The computer is also used for computer aided optimum design of harmonic filters for power systems.

INPUT: The inputs required for the simulation of power processors are the mathematical models of the system and the parameter values. When used to design a harmonic filter, optimally the inputs required are the levels of the harmonic voltages and currents to be reduced and the hardware components and power systems parameter values.

OUTPUT: The power processor simulation provides an initial assessment of the power equipment and system compatibility prior to installation. When used for filter synthesis, the computer will determine an optimum filter to improve the power quality, supplying nonlinear and sensitive loads from the same bus.

STATUS: Operational. Turbine-generator simulation and uninterruptible power supply (converter-inverter) completed. Awaiting funding for continuation of system simulation. Optimized filter design completed. Filter constructed and installed aboard oceanographic ship. Satisfactory operation obtained.

REFERENCES: None.

FURTHER INFORMATION: CR Young, Code 2781
DWTNSRDC, Annapolis, MD
AV 281-2467.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 21

NAME:	Aircraft Electrical Evaluation Facility.
DESIGN PROCEDURE:	Measure.
METHOD:	Simulation and measurement.

DESCRIPTION: Complete facilities to evaluate virtually any aircraft electrical system or system component. Capabilities include the following;

1) Temperature-altitude facilities for status and rotating equipment

2) Conditioned blast air and cooling oil sources

3) Vibration, shock, humidity, salt-spray, fungus, dust, and acceleration environmental simulation facilities

4) 13 programmable generator test stands

5) Digital data acquisition facilities

6) Open loop wind tunnel (230 knots maximum velocity)

7) Extensive inventory of aircraft electrical components for complete system reproduction

8) Two EMI screen rooms with automated receiving equipment

9) *Approximately 50 personnel (16 professional)*

INPUT:	Not applicable.
OUTPUT:	Not applicable.
STATUS:	Operational.
COMMENTS:	Not applicable.
REFERENCES:	Not applicable.
FURTHER INFORMATION:	JO Koegel, Code SY60 NATC, Patuxent River, MD AV 356-4701.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 22

NAME: Variable Characteristic, 3-Phase, 400-Hz Power Source.

DESIGN PROCEDURE: Measure.

METHOD: Active test equipment.

DESCRIPTION: A 3-phase, 60/400-Hz, 4500-VA power source which can be programmed to:

1) Vary steady-state voltage and/or frequency
2) Generate voltage and/or frequency transients
3) Generate high and low crest factor distortion

INPUT: Not applicable.

OUTPUT: Not applicable.

STATUS: Operational.

COMMENTS: This is a commercial unit manufactured by Elgar Corporation for simulation of MIL-STD-704A quality power. NATC and NOSC have similar equipment, except that NOSC has 7500-VA capability and equipment has been modified to give variable high and low crest factors with known harmonic content. It can also simulate ship power.

REFERENCES: Not applicable.

FURTHER INFORMATION: GR Danks, Code SY60
NATC, Patuxent River, MD
AV 356-4701.

RB Jordan, Code 9332
NOSC, San Diego, CA
AV 933-6157.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 23

NAME: Spike Voltage Generator.

DESIGN PROCEDURE: Measure.

METHOD: Active test equipment.

DESCRIPTION: A portable spike voltage generator designed to apply a 2500-volt, 40-microsecond spike with specified rise and decay times. The spike of required parameters (including energy content) can be applied at any selected part of the line voltage waveform, line-to-line or line-to-ground. The unit is used for testing and evaluating all kinds of electrical and electronic equipment to determine their resistance to such spike voltages.

INPUT: Not applicable.

OUTPUT: Not applicable.

STATUS: Operational. Presently in brassboard configuration. It has been used to test shipboard speed controllers for high-pressure brine systems, to test a TRIDENT 10-kW inverter. It is now being used by Varo, Inc, on frequency changer brassboards under development by the Navy.

REFERENCES: Spike parameters and source impedance are controlled by MIL-STD-1399 Section 103.

FURTHER INFORMATION: WH Kohlmann, Code 2773
DTNSRDC, Annapolis, MD
AV 281-2526.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 24

NAME:	Dynamic Load Simulator.
DESIGN PROCEDURE:	Measure.
METHOD:	Load simulation.

DESCRIPTION: A loading device for realistically evaluating power generation and conversion equipments in the development stage or prior to shipboard installation. The dynamic load simulator consists of a resistive load connected, through solid-state switching elements and a bridge rectifier, to the 3-phase power source under test. The solid-state switching elements are controlled by a small control card to simulate currents drawn by radars and sonars. The current waveforms are measured from actual equipment and used to program the control cards.

STATUS: Operational. Six 100-kW (peak load) dynamic load simulators have been constructed. They are packaged for transporting to remote locations. One of the units is presently being used by Varo, Inc, Dallas, Texas, to test their frequency changer brassboards being developed under Navy contract. Another unit is being used by Westinghouse, Lima, Ohio, for a similar purpose. The units can be paralleled for higher-capacity loading and more versatility.

REFERENCES:	None.
FURTHER INFORMATION:	CR Young, Code 2781 DTNSRDC, Annapolis, MD AV 281-2467. AP Nickley, Code 6158C NAVSEC, Wash, DC AV 222-1195

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 25

NAME:	High-Power Solid-State Device Tester.
DESIGN PROCEDURE:	Measure.
METHOD:	Active Test Equipment.

DESCRIPTION: An automated system for measuring the characteristics and parameters of high-power, solid-state devices under variable interdependent stresses. Measurements can be made on devices rated to 1000 amperes and 2500 volts.

INPUT:	Not applicable.
OUTPUT:	Not applicable.
STATUS:	Operational.
COMMENTS:	None.
REFERENCES:	None.
FURTHER INFORMATION:	W Kohlmann, Code 2773 DTNSRDC, Annapolis, MD AV 281-2526.

TABLE B-1. (Continued)

Electromagnetic Environmental Design Procedure 26

NAME:	Transmission Cable Shielded Room.
DESIGN PROCEDURE:	Measure.
METHOD:	Test facility.

DESCRIPTION: Shielded room and isolation measurement facilities for electrostatic and electromagnetic analysis of transmission cables.

INPUT:	Not applicable.
OUTPUT:	Not applicable.
STATUS:	Operational.
REFERENCES:	None.
COMMENTS:	None.
FURTHER INFORMATION:	G Rodriquez, Code 2772 DTNSRDC, Annapolis, MD AV 281-3118.

TABLE B-1. (Continued

Electromagnetic Environmental Design Procedure 27

NAME:	500 kW Variable Frequency M-G Set.
DESIGN PROCEDURE:	Measure.
METHOD:	Active Test Equipment.

DESCRIPTION: Variable voltage, variable frequency, 500-kW reversible motor-generator. This facility can supply adjustable 250-V dc or adjustable 450-V ac over a wide frequency range sufficient to cover the ±5% variations specified for type 1 power in MIL-STD-1399, sec 103.

INPUT:	Not applicable.
OUTPUT:	Not applicable.
STATUS:	Operational.
COMMENTS:	None.
REFERENCES:	None.
FURTHER INFORMATION:	CR Young, Code 2781 DTNSRDC, Annapolis, MD AV 281-2467.

TABLE B-1. (Continued).

Electromagnetic Environmental Design Procedure 28

NAME: Shipboard Power Measurements.

DESIGN PROCEDURE: Measure.

METHOD: Passive test equipment.

DESCRIPTION: Complete instrumentation system for measuring shipboard power system parameters. Included in this facility are many unique instruments developed by personnel at DTNSRDC. Examples of such "one of a kind" instruments are:

1) Transient (spike) voltage recorder (continuously monitors the ship's power system and automatically records high-frequency voltage spikes, photographing the wave shapes from oscilloscope traces)

2) High-accuracy (expanded scale) 30-voltage recorder, current and frequency recorders

3) Voltage percent modulation recorder

4) Voltage distortion recorder

In addition there are several real-time analyzers and a broadband impedance measuring system. This system is designed to measure and record impedances and phase angles of active shipboard power systems automatically at multiple points over a wide range of frequencies.

INPUT: Not applicable.

OUTPUT: Not applicable.

STATUS: Operational.

COMMENTS: None.

FURTHER INFORMATION: CR Young, Code 2781
DTNSRDC, Annapolis, MD
AV 281-2467.

APPENDIX C: NEEDED EM-POWER TOOLS

At the EM-Power Workshop at NRL, the participants (listed in table 1-2) were asked what tools are needed to improve their capability to select, arrange, analyze, and measure in EM-Power. Approximately 30 tools were identified and discussed at the workshop. These have been grouped under the headings of system engineering (includes select and arrange), analysis, measurement, and other (personnel, charters, etc). The name of the facility suggesting the tool is given with the name of the contact; however, for almost every tool there were one or more additional facilities supporting the need of the tool in their work. The requests for better data were put forward with the greatest energy. Apparently, poor data is a real problem. The Navy EM-Power technical community has historically put heavy resources into measurement and has been relatively successful in this area. There was no shortage of ideas on what was needed to improve the Navy's capability to measure EM-Power. Analytical procedures have been little used by the Navy EM-Power technical community, and few ideas other than computer simulation for analysis were forthcoming. On visits to the various facilities, there was considerable interest, and there was some skepticism in the newer analytical techniques discussed.

System Engineering (includes select and arrange)

A need exists to apply the concepts of modern system theory to Naval electric power systems (BJ Wilson, NRL) and to take a broader and more disciplined system engineering approach to solving EM-Power problems (J Foutz, NOSC). Opportunities (such as the workshop) to discuss common problems and to hear how others are approaching/solving these problems are very beneficial (near consensus). Computer modeling and simulation of the electrical power system and the total power/load system along with other systematic approaches (ie, the prediction methodology discussed next under analysis) have the greatest potential for solving problems before the problem is incorporated into hardware (majority of workshop).

Analysis

The prediction methodology developed by NAVSEC/NUSC/University of Pennsylvania for predicting EMC problems below decks needs to be refined and expanded including generating new models to support the prediction methodology. This methodology is part of the TRIDENT EMC Plan (PJ Johnson, NUSC).[1-5]

The NASA program Modeling and Analysis of Power Processing Systems (MAPPS) has high potential application to Navy electrical power systems and electronic equipment power supplies. This needs to be demonstrated and, if effective, the Navy and Navy contractor EM-Power community trained in its use (J Foutz, NOSC).

Computer models and data needed for these models are needed for aircraft (JD Segrest, NADC), for ships (CR Young, DTNSRDC), for shore facilities (JL Brooks, CEL), for electronic equipment (J Foutz, NOSC; JH Jentz, NAFI), and for integrating the electronics and weapon loads with the electrical power system (PJ Johnson, NUSC; JR Hoffler, NAVSEC).

Other analytical techniques such as the design oriented circuit analysis techniques developed by Dr Middlebrook at the California Institute of Technology and the State Plane and

other techniques for nonlinear circuits developed by Dr Wilson of Duke University have been demonstrated effective for switching regulator power supply analysis and have potential as an analytical technique for other EM-Power applications (J Foutz, NOSC).

Measurement

Modern state-of-the-art measurement equipment (A/D and special transducer sensors, digital data processing, storage and retrieval, microprocessor controlled) for steady state and transients is needed for aircraft (BJ Wilson, NRL; JD Segrest, NADC), ships (CR Young, NSRDC), shore (JL Brooks, CEL), and electronics (J Foutz, NOSC). Techniques to correlate electric power system and electronic system events need to be developed to determine cause and effect interactions (CR Young, NSRDC; JL Brooks, CEL). Efficient measurement techniques to determine the transfer function of system components are needed (JL Brooks, CEL).

Measurement techniques for power line filters that will allow prediction of filter response in systems are needed (R Plew, NWSC). Standard measurement techniques are needed to establish the load signature of nonlinear loads (JH Jentz, NAFI). Measurement techniques that characterize power system faults are needed (JL Brooks, CEL). Better load simulators to simulate the harmonic currents, current pulses, power factor, and negative input impedance of loads are needed for aircraft (G Danks, NATC; JD Segrest, NADC) and ships (CR Young, NSRDC).

Data

Improved MIL-STD-461 test methods and data are needed to support the prediction methodology (PJ Johnson, NUSC). Accurate configuration data, EM-Power data, accurate characterization of power system/load components, load sensitivity information, and mission profile power variation data are needed for aircraft (JD Segrest, NADC; G Danks, NATC), ships (CR Young, DTNSRDC; PJ Johnson, NUSC; JR Hoffler, NAVSEC), and shore (JL Brooks, CEL). Data needs of the users need to be better reflected in general specifications and standards (J Foutz, NOSC). A general data bank on Naval facilities power systems is needed (JL Brooks, CEL). A handbook that describes the various power systems used on various platforms and the options and tradeoff considerations is needed (JH Jentz, NAFI).

Standard Navy data bases such as 3-M data need to be made more credible and expanded to give more information needed by the EM-Power technical community.

Personnel

The Navy needs to recruit several young professionals with state-of-the-art training in Power Electronics (J Foutz, NOSC).

Charters

The various organizational charters in EM-Power need to be better stated. There appears very little conflict in what the working community regards their charter, but this is unclearly stated in official documents.

APPENDIX D: SPECIFICATIONS AND STANDARDS – DEFINITIONS

From MIL-STD-961, OUTLINE OF FORMS AND INSTRUCTIONS FOR THE PREPARATION OF SPECIFICATIONS AND ASSOCIATED DOCUMENTS, 22 SEPT 1975:

This standard supersedes Chapter V of the Defense Standardization Manual DSM 4120.3-M Jan 1972. It controls the preparation of specifications, as discussed in this report, that are not program peculiar. (Preparation of program peculiar specifications is controlled by MIL-STD-490). MIL-STD-961 defines a specification as:

a. A Specification is defined as a document intended primarily for use in procurement, which clearly and accurately describes the essential technical requirements for items, materials, or services, including the procedures by which it will be determined that the requirements have been met. Specifications for items and materials may also contain preservation-packaging, packing, and marking requirements.

b. Specifications for procurement shall state only the actual minimum needs of the Government and describe the supplies and services in a manner which will encourage maximum competition and eliminate, insofar as possible, any restrictive features which might limit acceptable offers to one contractor's products or the products of a relatively few contractors.

c. A specification shall not include contractual requirements which are properly a part of the contract. These are covered by ASPR and other contractual clauses. Contractual and administrative provisions considered essential for procurement, including data items, may be indicated as "ordering data" or "features to be included in bids or in the contract," in Section 6. This provision shall be exercised with caution and limited to essential matters.

Data requirements for specifications are discussed in the General Requirements section of MIL-STD-961 as follows:

Data Requirements. In many instances, specifications will identify deliverable items of data in connection with task elements cited in other sections of the specification. The description of these deliverable items of data must be contained in a Data Item Description (DID) (DD Form 1664) normally found in the Department of Defense Authorized Data Lists (TD-3) (DODADL). In those instances the specification (Section 6) will identify the items of data by paragraph title and DID number (see 5.6.5). In the case of data specifications or other specifications where it is not possible to separate the format and contents requirements for deliverable items of data for inclusion in a DID (DD Form 1664) (quality assurance provisions, first article test reports, certificates of compliance, operating instruction, etc.) the data items may be described and included directly in the specification and any DID developed for use with the specification will only reference the pertinent paragraphs. The DID's identified in the specification will be prepared by or in coordination with the preparer of the specification in accordance with the instructions in DODI 5010.12 at the time the specification is prepared and circulated with the specification through the coordination cycle. It should be noted that any item or data described in a DID must have corresponding direction in the specification to have the contractor generate the basic information required for the deliverable item of data. The requirement for generation of data shall be included in Section 3. Delivery of any of the data requirements stated in a specification can be obtained only when specified on DD Form 1423, Contract Data Requirements List, in the contract. Specifications will not contain requirements for the delivery of data. Requirements will be confined to generation of data and description of the content and format where necessary.

Rights in data. The acquisition of rights in technical or other data shall not be made through the medium of a specification. See ASPR, Section IX, Part 2 for procedures for obtaining such rights through appropriate contract clauses.

MIL-STD-962, OUTLINE OF FORMS AND INSTRUCTION FOR THE PREPARATION OF MILITARY STANDARDS AND MILITARY HANDBOOKS, 22 SEPT 1975

This standard supersedes Chapter VI of the Defense Standardization Manual DSM 4120.3-M Jan 1972. It controls the preparation of standards and handbooks, as discussed in this report. MIL-STD-962 defines standards and handbooks as:

Standard. A document that establishes engineering and technical limitations and applications for items, materials, processes, methods, designs and engineering practices.

a. Standards define terms, establish codes and document practices, procedures and items selected as standard for design, engineering and supply management operations. Military standards shall not be used as the medium for imposing administrative requirements on contractors.

b. Standards are documents created primarily to serve the needs of designers, and to control variety. They may cover materials, items, features of items, engineering practices, processes, codes, symbols, type designations, definitions, nomenclature, test, inspection, packaging and preservation methods and materials, define and classify defects, and standardize the marking of material and item parts and components of equipment, etc. Standards represent the best solution for recurring design and engineering and logistics problems with respect to the items and services needed by the military services.

c. Standards are used to standardize one or more features of an item such as size, value, detail of configuration, etc. In equipment specifications, they are referenced to standardize on those design and testing requirements which are essential to interchangeability, compatibility, reliability, and maintainability. They are prepared to provide the designer with the descriptions and the data normally required for selection and application. Standards disclose or describe the technical features of an item in terms of what it is and what it will do. In contrast, the specification for the same item describes it in terms of the requirement for procurement. Reference to other documents in standards to complete a description should be resorted to only when it is impracticable to do otherwise.

Military handbooks. Military handbooks (MIL-HDBK) are documents containing reference data or guidance for use in design, engineering, production, procurement, and supply management operations. Military handbooks are used for the presentation of general information, procedural and technical use data or design information related to commodities, processes, practices and services related to the Defense Standardization Program which shall be used in supply management operations and in the preparation of specifications and standards. These handbooks also provide industry with reference material that will serve further the Standardization Program. The use of handbooks as references is optional. Certain handbooks are completely inappropriate for referencing in other standardization documents.

Data requirements for standards are discussed in the General Requirements section of MIL-STD-962 as follows:

4.1.2 Data requirements. For requirements covering the preparation of DD Form 1664, see DoD Instruction 5010.12. Where practicable, data, format, and content requirements shall be selected from existing DD Forms 1664 when preparing or revising a standard. Data requirements may be described and included directly in a bookform MIL-STD where it is impracticable to separate the format and content of data products from the standard for direct inclusion in a DD Form 1664, such as data requirements covering quality assurance provisions. When data format and content requirements are contained in a DD Form 1664, such requirements shall not appear in the standard, except that deliverable data required shall be identified in an associated appendix. Identification shall include the corresponding DD Form 1664 number. In those instances where data requirements are included indirectly in the standard, the DD Form 1664 shall describe the data by reference to the standard. The location of these data requirements in the standard shall be listed in the associated appendix, including identification of the corresponding DD Form 1664. Delivery of any of the data requirements stated in a standard can be obtained only when specified on DD Form 1423 in the contract. Standards shall not contain requirements for delivery of data. Requirements shall be confined to generation of data and description of the content and format where necessary.

MIL-STD-490, SPECIFICATION PRACTICES, 30 OCT 1968
CHANGE NOTICE 1, 1 FEB 69, CHANGE NOTICE 2, 18 MAY 72

This standard establishes the format and contents of specifications for program peculiar items, processes and materials.

Program peculiar is defined as:

Program peculiar items, processes and materials as used in this standard, include all items, processes and materials conceived, developed, reduced to practice or first documented for the development, procurement, production, assembly, installation, testing or support of the system/equipment/end item (including their components and supporting items) developed or initially procured under a specific program.

Change Notice 2 strengthens the definition for Army purposes.

Data requirements are not discussed in the standard.

Contractual and administrative requirements are discussed in the requirements section as follows:

Contractual and administrative requirements. A specification shall not include contractual requirements which are properly a part of the contract; such as cost, time of delivery, instruction on reworking or resubmitting rejected items or lots, method of payment, liquidated damages, provision for items damaged or destroyed in tests, etc. Contractual, administrative, and warranty provisions such as those covered in general provision of contracts, shall not be made part of the requirements in the specification. Contractual and administrative provisions

not covered in the general provisions, but considered essential procurement, may be indicated as "ordering data" or "features to be included in bids or in contract" in Section 6. This provision shall be exercised with caution and limited to essential matters.

ARMED SERVICE PROCUREMENT REGULATION (ASPR)

DPC #75-8 21 MAY 1976

Recent studies have indicated that one of the explanations for increasing acquisition cost is the misapplication of specifications and standards in both requests for proposals and subsequent contractual arrangements. In many cases, the problem lies not completely with the documents themselves, but to a large degree with the over- or misapplication of requirements. As a result, the policy established in ASPR 1-1201, has been changed to emphasize the need for a "scrub and tailor" of specifications and standards to amplify and facilitate the requirement that purchase descriptions state only the actual minimum needs of the Government.
Replacement page: 1:177

GENERAL PROVISION

Part 12 – Specifications, Plans, and Drawings

1-1201 General.

(a) Plans, drawings, specifications or purchase descriptions for procurements shall state only the actual minimum needs of the Government and describe the supplies and services in a manner which will encourage maximum competition and eliminate, insofar as possible, any restrictive features which might limit acceptable offers to one supplier's product, or products of a relatively few suppliers. Items to be procured shall be described by reference to the applicable specifications or by a description containing the necessary requirements. Referenced specifications and standards shall be tailored in their application. Tailoring consists of the exclusion of those sections, paragraphs or sentences of individual specifications and standards not required for a specific procurement so that each document applied states only the minimum requirements of the Government. Such tailoring need not be made a part of the basic specification or standard but will vary with each application dependent upon the nature of the procurement. When specifications are cited, all amendments or revisions thereof, applicable to the procurement, should be identified and the identification shall include the dates thereof. Drawings and data furnished with solicitations shall be clear and legible.

(b) Many specifications cover several grades or types, and provide for several options in methods of inspection, etc. When such specifications are used, the solicitation shall state specifically the grade, type, or method of inspection, etc., on which bids or offers are to be based.

APPENDIX E: DISCUSSION OF MIL-E-5400

ELECTRONIC EQUIPMENT, AIRBORNE, GENERAL SPECIFICATION FOR

DESCRIPTION. This specification covers the general requirements for airborne electronic equipment for operation primarily in piloted aircraft. The detailed performance and test requirements for a particular equipment shall be as specified in the detail specification for that equipment.

DISCUSSION. Figure E-1 is the EM-Power specification tree for MIL-E-5400R. Only general requirements are given in MIL-E-5400 with all quality assurance provisions except test methods and interference tests left for the detailed equipment/system specification.

If quality assurance provisions are not stated in the detailed specification, they are prepared by the contractor and sent to the procuring activity for approval. Figure E-2 is a flowchart that can aid the writer of the detailed specification in providing for EM-Power requirements.

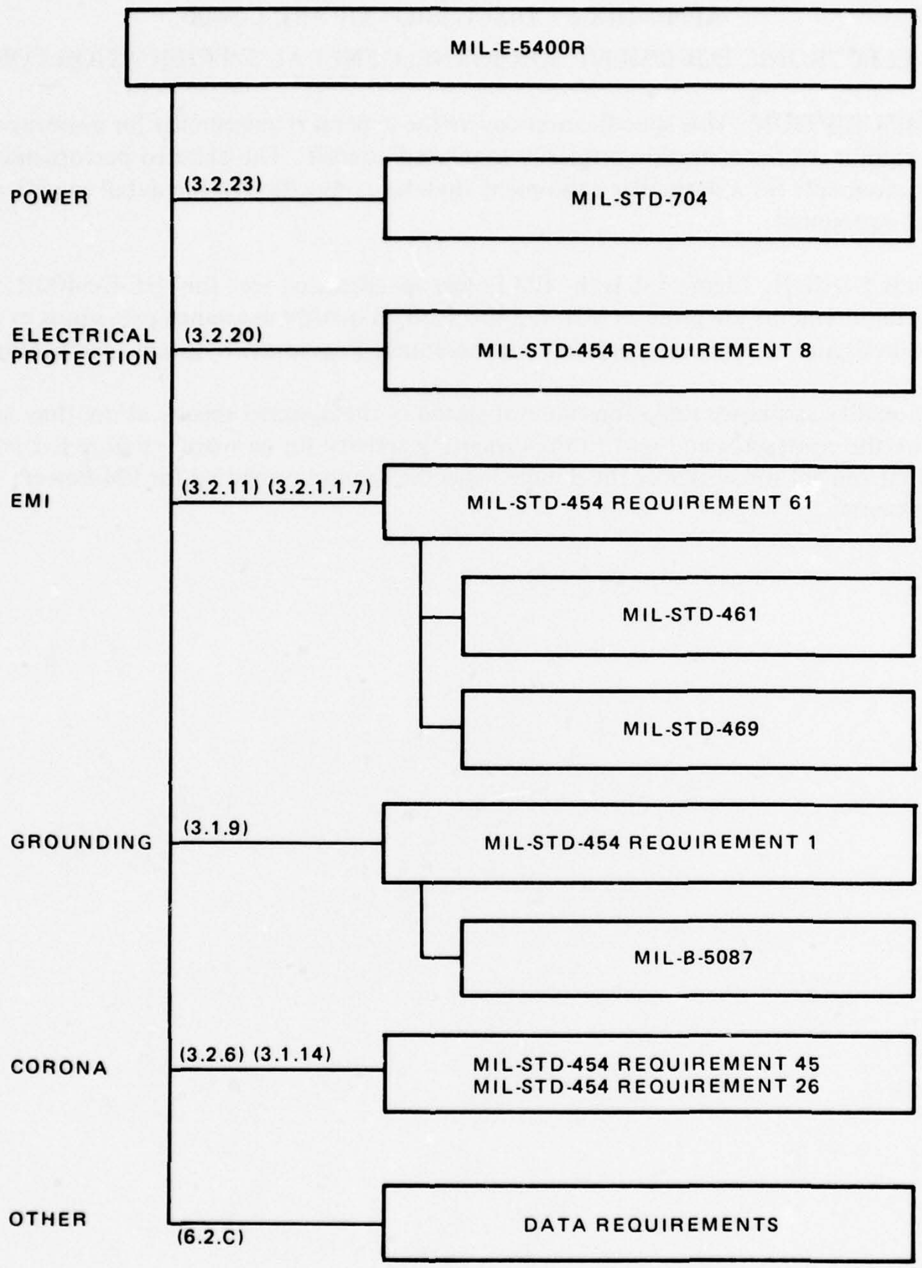


Figure E-1. MIL-E-5400R EM-power specification tree.

A. CONTINUITY OF POWER

Is the impact on the system caused by loss of electrical power for durations defined in MIL-STD-704 (up to 7 seconds) acceptable?

Yes: No action required.

No: Determine circumvention method to be used and specify in detailed equipment/system specification. Add quality assurance provisions.

B. POWER

MIL-STD-704 power options:

a. 270Vac

b. 115/200Vac, 3-phase

c. 115/Vac, 1-phase

d. 28Vdc

e. 230/400Vac, 3-phase

f. 230Vac, 1-phase

1. Is the equipment/system to operate on present aircraft and 1980+ aircraft using the Advanced Aircraft Electrical System (OR-WSL04)?

Yes: Specify that the equipment/system must operate on options a (270Vdc) and b (115/200Vac 3-phase power).

No: Not recommended except under special conditions since this usually adds weight and added fuel consumption to aircraft. Select other options only if indicated in trade off study.

2. Is performance required in emergency mode?

Yes: Specify in equipment/system specification.

No: Default condition. No action required.

3. Is performance required during over/under voltage conditions?

Yes: Specify in equipment/system specification.

No: Default condition. No action required.

4. Is equipment damage with low input voltage satisfactory?

Yes: Default condition. No action required.

No: Add low input voltage requirement (recommended).

Figure E-2. Flowgraph of MIL-E-5400R EM-power requirements.

Low input voltage requirement:

Section 3 Requirement. The equipment shall not be damaged or degraded by low input voltages (from zero volts to specified operating voltage).

Section 4 Quality Assurance. Input voltage shall be increased from zero volts to nominal operating voltage, decreased to zero volts, and then increased again to the nominal operating voltage. The rate of change of voltage shall be constant and no greater than 10 volts/minute. The equipment shall have no indication of degraded performance when the input voltage is within its specified steady-state operating range.

Comment. This requirement is essential for systems that contain switching regulator power supplies since they can be destroyed by low input voltage if not properly protected. Equipment containing relays and dc-to-ac converters can also be damaged by low input voltage. Equipment with high-efficiency power conversion may draw excessive current, opening fuses and circuit breakers at low input voltage. These effects can be easily and inexpensively avoided by proper design. This requirement ensures that the equipment is properly designed.

5. Are secondary failures due to primary failures satisfactory?

   Yes: Default condition. No action required.

   No: Add power supply sequencing and output polarity reversal requirement (recommended).

Power supply sequencing and output polarity reversal:

Section 3 Requirements: No power supply load shall be damaged or fail to operate as a result of the sequence in which required power is applied. No dc power supply output shall be capable of a polarity reversal of more than 1 volt in the energized or nonenergized condition. In the nonenergized condition, the power supply shall provide up to 10% of its rated current without damage in a forced polarity reversal condition. No load shall be damaged by a polarity reversal of 1 volt on any power-supply output.

Section 4 Quality Assurance. None.

Comment. Power sequencing and output polarity reversal specifications control a frequent source of reliability degradation in solid state circuits where circuits are overstressed or failed during power turn-on or turn-off or when a short occurs on one power supply output. Loads connected to that power supply output can cause the polarity to reverse, stressing other circuits if protection is not provided. Since power supplies turn on, turn off, and fail in a random manner, any circuit that depends on power sequencing for survival can suffer early failures. This requirement becomes more important in EMP environments that may cause random activation of protection circuits. The requirement can usually be met at no cost impact if the contractor knows it is a requirement. Normally, the cost of section 4 tests is not warranted since the problem, if there is one, will usually surface during normal development efforts.

Figure E-2. (Continued)

6. Are unbalance loads and low power factor loads acceptable:

Yes: Default condition. No action required.

No: Reinstate applicable MIL-STD-704A sections removed from MIL-STD-704B or write new requirements.

7. Is data required for load power analysis:

Yes: Write requirement into equipment/system specification or contract data requirements.

No: Default condition. No action required.

8. Is quality assurance of power desired?

Yes: Write quality assurance provisions. Present specifications contain no quality assurance provisions except for voltage spike test (damage only, operation not required in presence of spike) in MIL-STD-704B.

No: Not recommended.

C. ELECTRIC PROTECTION

1. Is the Class 2 protection philosophy adequate? (Protect for fire, smoke, explosion, and arc-over only, except for critical circuits, or design inherent overloads which are protected by means of operator-accessible resettable circuit breakers.)

Yes: Default condition. No action required.

No: Specify protection philosophy in equipment/system specification.

2. Is quality assurance of protection desired?

Yes: Write quality assurance provisions.

No: Default condition. Probably satisfactory in most cases.

D. EMI

Default condition 1: The full MIL-STD-461 requirements are specified, with the contractor determining the equipment class and preparing the quality assurance provisions for the approval of the procuring activity.

1. Is fault condition 1 satisfactory?

Yes: No action required.

No: Tailor MIL-STD-461 in equipment/system specification or write requirements, and write quality assurance provisions. Caution: To avoid common faults in the design of power supplies and EMI filters, it is mandatory that the equipment operate through the spike test of MIL-E-6051, the CS01, CS02, and CS06 susceptibility tests of MIL-STD-461,

Figure E-2. (Continued)

and not be damaged by the spike test in MIL-STD-704B. The requirement and quality assurance tests for these should be mandatory and never waived.

Default condition 2: Paragraph 3.2.1.1.7 requires that interconnecting leads involving circuits susceptible to radiation or capable of radiation be shielded and of low-impedance design. All other connections (such as power) should be well shielded and bypassed internally. There are no quality assurance provisions.

2. Is default condition 2 satisfactory?

Yes: No action required.

No: Write requirements and quality assurance provisions.

D. GROUNDING

All grounding requirements in MIL-E-5400R are safety-oriented only. There is no control of signal ground.

1. Is no control of signal ground acceptable?

Yes: No action required (not recommended).

No: Determine signal ground philosophy including effects of common-mode noise, lighting, and/or EMP effects, etc., and write requirements into equipment/system specification.

E. CORONA

1. Are MIL-STD-454 Requirement 45 provisions satisfactory? (There are no quality assurance provisions.)

Yes: No action required.

No: Tailor requirements and, if desired, add quality assurance provisions.

F. DATA

Are data users provided with all data, as reflected in the Contractor Data Requirements (DD Form 1423), needed in the various phases of the acquisition process?

Yes: No action.

No: Identify users and reflect needs in DD Form 1423.

Figure E-2. (Continued).

APPENDIX F: SHIP SPECIFICATION REVIEW

The specifications relating to the shipboard electric power system and electronics interface are reviewed below. The same specifications are also reviewed for coverage of the signal-common interface between electronic equipments. The primary specification is the General Specification for Ships of the United States Navy.[F-1] This specification and all those deriving from it are reviewed. Other specifications, not in the specification tree, but candidates for inclusion, are then reviewed. A description of each specification is given and then its relation to this project is discussed. There are several other specifications that impact on the Electric Power/Electronics/Signal-common interfaces that could not be reviewed in the limited time/funding constraint of this project.

NAVSHIPS 0902-001-5000 GENERAL SPECIFICATIONS FOR SHIPS OF THE UNITED STATES NAVY[F-1]

DESCRIPTION

This specification applies to work under the cognizance of the Naval Ship Systems Command. The purpose is to describe the requirements for new ships which best meet the needs of the US Navy and to secure standardization of practices, materials, and equipment. It is intended to be kept current with the state of the art and with experience gained from deficiencies discovered during ship acquisition and operation. The specification is divided in sections compatible with the ship work breakdown structure.

Of primary interest in this project are Sections 300, General Requirements for Electric Plant, and Section 400, General Requirements for Electronic Systems. The electronic system section pertains mostly to platform related electronics such as interior communications and alarm and warning systems.

The specification tree resulting from NAVSHIPS 0902-001-5000 is shown in figure F-1. The specification also directly controls some parameters without referring to external specifications. For example, dc power characteristics are described (Section 300b), additional limits to MIL-STD-1399 Sec 103 are placed on transient voltages caused by motor loads (Section 3022), and there are two statements on EMI:

300c. Electric equipment shall be capable of operating simultaneously with electronic equipment without causing electromagnetic interference.

400c. Electromagnetic coupling – Equipments which can interact due to electromagnetic or electrostatic fields shall be separated as far as practicable. Equipment and devices which are adversely affected by electromagnetic coupling shall be located and oriented for minimal coupling.

Magnetic fields – Electronic equipment shall be installed in magnetic fields having field densities of less than 5 oersteds unless the equipment is specifically designed to operate in greater field densities. The design parameter of the equipment shall limit ambient field densities above 5 oersteds.

F-1. NAVSHIPS 0902-001-5000, General Specifications for Ships of the United States Navy, 1 Jan 1975.

NAVSHIPS 0902-001-5000
SPECIFICATION FOR SHIPS OF THE US NAVY

- MIL-STD-1399 SEC 103
  INTERFACE STANDARD FOR SHIPBOARD SYSTEMS -
  ELECTRICAL POWER, ALTERNATING CURRENT

- MIL-I-983
  INTERIOR COMMUNICATIONS EQUIPMENT
  NAVAL SHIPBOARD, BASIC DESIGN REQUIREMENTS FOR

- NAVSHIPS 0967-000-0100
  ELECTRONICS INSTALLATION AND MAINTENANCE
  BOOK (EIMB) - GENERAL

- NAVSHIPS 0967-000-0110
  ELECTRONICS INSTALLATION AND MAINTENANCE
  BOOK (EIMB) - INSTALLATION STANDARDS

- C110.1
  RECOMMENDED PRACTICE FOR ELECTRIC
  INSTALLATIONS ON SHIPBOARD

- MIL-STD-1310
  SHIPBOARD BONDING, GROUNDING, AND OTHER TECHNIQUES
  FOR ELECTROMAGNETIC COMPATIBILITY AND SAFETY

- MIL-STD-1605 (SHIPS)
  PROCEDURES FOR CONDUCTING A SHIPBOARD ELECTROMAGNETIC
  INTERFERENCE (EMI) SURVEY (SURFACE SHIPS)

Figure F-1. Specification tree, NAVSHIPS 0902-001-5000

DISCUSSICN

In reviewing the specification, the following observations are made:

(a) There is a clear specification connection to MIL-STD-1399 Sec 103 which controls the electrical power interface and MIL-STD-1310 which controls bonding and grounding.

(b) There are no clear specification paths to key electronic and EMI specifications such as MIL-E-16400, MIL-F-18870, MIL-STD-461 and Electronic Interface Sections of MIL-STD-1399.

(c) Electrical tests performed during system integration are mostly static in nature. (Voltage dips caused by motor starts is one exception.) The result is virtually complete reliance on compatible interface specifications and adequate equipment level testing – a condition that does not exist.

(d) Data are collected only if there are gross deficiencies in the particular installation. Data for system design and modification are not generated.

(e) There are no controls on EMC management (of the MIL-E-6051 or MIL-HBK-237 type).

(f) There is no control of the signal-ground interface between electronic equipments.

The specifications identified in the NAVSHIPS 0902-001-5000 specification tree are individually discussed. Some other specifications that should be in a complete specification tree, but are not, are also discussed.

MIL-STD-1399 SECTION 103 INTERFACE STANDARD FOR SHIPBOARD SYSTEMS, ELECTRIC POWER, ALTERNATING CURRENT[F-2]

DESCRIPTION

The specification controls the voltage, frequency, and continuity characteristics of the shipboard AC Electrical Power System. The interface is controlled at the input terminals of the power consuming equipment or subsystem. It places constraints on the user of compatibility, power factor, pulsed load, load unbalance, waveform, protection, large motors, preference as to type of power, and grounding. A new draft (to be section 300) is just entering the review cycle (Oct 1976).

DISCUSSION

The standard is clearly invoked by NAVSHIPS 0902-001-5000 and several electronic equipment specifications. The specification is clear in its requirements with one exception: an energy content or similar constraint on the 25 000-V spike is required. The specification approach used in MIL-STD-704B (Electric Power, Aircraft, Characteristics of) could be used.

F-2. MIL-STD-1399A (Navy), Interface Standard for Shipboard Systems, 20 Dec 1972: a) Section 103, Electric Power, Alternating Current, 1 Dec 1970; b) Section 300, Electric Power, Alternating Current, Draft Copy of 07/14/76 (revisions of Section 103 with number change to be compatible with ship work breakdown structure).

MIL-I-983 INTERIOR COMMUNICATION EQUIPMENT, NAVAL SHIPBOARD, BASIC DESIGN REQUIREMENTS FOR[F-3]

DESCRIPTION

This specification covers the basic design requirements, test and operating conditions for interior communication equipment to be used in Naval ships. The purpose of this specification is to secure uniformity of practice, quality of materials and workmanship necessary to meet the special requirements for equipments to be installed in ships of the United States Navy.

DISCUSSION

Of the three general electronic specifications for electronic equipment (MIL-I-983, MIL-E-16400, MIL-F-18870) this is the only one in the NAVSHIPS 0902-001-5000 specification tree. It has gone the longest without revision (22 Dec 67 as compared to 24 Dec 74 and 25 Apr 75). As the result, it has not kept up with current design and test philosophy. The only EMI specification called out is MIL-I-16910. The power-supply tolerances called out are not compatible with Type I ship service power, as controlled by MIL-STD-1399, Section 103. (For example, single -phase 115-V ship-service voltage limits are 107 V to 123 V, while MIL-I-983 equipment is only designed and tested for limits of 109 V to 121 V). There is no requirement or test for the 2500-V spike voltage. Signal ground is partially controlled; if grounded, it is grounded to ship's hull at one point only. Quality Assurance testing is primarily static and data obtained are insufficient for system design.

NAVSHIPS 0967-000-0100 and -0110 ELECTRONICS INSTALLATION AND MAINTENANCE BOOK (EIMB)[F-4,5]

DESCRIPTION

The Electronics Installation and Maintenance Book (EIMB) was established as the medium for collecting, publishing, and distributing, in one convenient source document, subordinate maintenance and repair policies, installation practices, and overall electronic equipment and material-handling procedures.

Since its inception, the EIMB has been expanded to include selected information of general interest to electronic installation and maintenance personnel. These items are such as would generally be contained in textbooks, periodicals, or technical papers, and form (along with the information cited above) a comprehensive reference document. In application, the EIMB is to be used for information and guidance by all military and civilian personnel involved in the installation, maintenance, and repair of electronic equipment under the cognizance, or technical control, of the Naval Ship Systems Command (NAVSHIPS). The

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F-3. MIL-I-983E, Interior Communications Equipment, Naval Shipboard, Basic Requirements for, 15 Aug 1966, and Amendment -1, 22 December 1967.

F-4. NAVSHIPS 0967-000-0100, Electronics Installation and Maintenance Book, General, May 1973: Change 1, Sept 1974.

F-5. NAVSHIPS 0967-000-0110, Electronics Installation and Maintenance Book, Installation Standards, August 1963: Change 6, Oct 1972.

information, instructions, and procedures in the EIMB supplement instructions and data supplied in equipment technical manuals and other approved maintenance publications.

GENERAL INFORMATION HANDBOOKS

General	0967-000-0100
Installation Standards	0967-000-0110
Electronics Circuits	0967-000-0120
Test Methods and Practices	0967-000-0130
Reference Data	0967-000-0140
EMI Reduction	0967-000-0150
General Maintenance	0967-000-0160

EQUIPMENT ORIENTED HANDBOOKS

Communication	0967-000-0010
Radar	0967-000-0020
Sonar	0967-000-0030
Test Equipment	0967-000-0040
Radiac	0967-000-0050
Countermeasures	0967-000-0070

DISCUSSION

The total EIMB Handbook series is listed above. Only the first two books in the table are called out in the NAVSHIPS 0902-001-5000 specification tree. The books contain information and guidance only, not specification control. There is virtually no guidance in the General Information handbooks on the Power/Electronic interface. The one exception is the safety discussion on shipboard ungrounded power in the General (-0100) book. The EMI Reduction Book[F-6] is not in the NAVSHIPS 0902-001-5000 specification tree. It contains very little guidance for interference on the Electric Power/Electronics/Signal-Common interface.

F-6. NAVSHIPS 0967-000-0150, Electronics Installation and Maintenance Book, Electromagnetic Interference Reduction, June 1972.

C11C.1 RECOMMENDED PRACTICE FOR ELECTRICAL INSTALLATIONS ON SHIPBOARD[F-7]

DESCRIPTION

These recommendations were drawn up to serve as a guide for the equipment of merchant vessels with an electric plant system and electric apparatus for lighting, signaling, communication, power, and propulsion. They indicate what is considered good engineering practice with reference to safety of the personnel and of the ship itself as well as reliability and durability of the apparatus.

DISCUSSION

With respect to the Electric Power/Electronics Interface, no information other than that already provided in MIL-STD-1399, Sec 103, or MIL-STD-1310 is given. With respect to signal common, it recommends that the secondary of all instrument transformers be grounded.

MIL-STD-1310 SHIPBOARD BONDING, GROUNDING, AND OTHER TECHNIQUES FOR ELECTROMAGNETIC COMPATIBILITY AND SAFETY[F-8]

DESCRIPTION

This standard sets forth methods for shipboard bonding, grounding, and the utilization of nonmetallic materials for the purpose of electromagnetic interference (EMI) reduction and the protection of personnel from electrical shock. In addition, methods for the installation of shipboard ground systems are also provided.

DISCUSSION

This is one of the few specifications or standards that discuss signal ground. The signal ground system for NTDS (digital) equipments is clearly defined. No deviations are allowed. Engineering considerations associated with this approach are discussed elsewhere. There are no data provisions in the standard.

F-7. ANSI C110.1 – 1972 and IEEE STD 45-1971, An American National Standard, IEEE Recommended Practice for Electric Installations on Shipboard, Approved July 11, 1972, by the American National Standards Institute.

F-8. MIL-STD-1310C (Navy), Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety, 30 Nov 1973.

MIL-STD-1605 (SHIPS PROCEDURES FOR CONDUCTING A SHIPBOARD ELECTROMAGNETIC INTERFERENCE (EMI) SURVEY (SURFACE SHIPS)[F-9]

DESCRIPTION

This standard provides detailed procedures for conducting an electromagnetic interference (EMI) survey aboard surface ships. An EMI survey is required for new construction ships and ships receiving overhauls or other major repair work that changes the electromagnetic configuration.

DISCUSSION

The standard is concerned with radiated emissions in higher frequency ranges only and makes no conducted-emission measurement or low-frequency (below 150-kHz) measurements. Ship's own equipment is used to check for susceptibility sensitivity. The standard does provide clear provisions for data collection and reporting.

MIL-HDBK-237 ELECTROMAGNETIC COMPATIBILITY/INTERFERENCE PROGRAM REQUIREMENTS[F-10]

DESCRIPTION

This handbook provides criteria for establishing, managing, and evaluating an EMC program on electronic, electrical, and electromechanical equipments, subsystems, and systems. It provides EMC guidance to the project officer. The handbook is for use by procuring activities, contractors, and testing facilities as follows:

(a) To assist in the determination of the EMC requirements needed in equipment, subsystems, and system specifications, contract work statements, and other contractual documents.

(b) To be applied to any system or major equipment and to any life-cycle phase when an EMC program is being defined, evaluated, or changed. The program may include deletions or additions with changes tailored and approved to individual sections or requirements, as appropriate.

The criteria in this handbook may be tailored in the request for proposal (RFP) or contract work statement to form a basis for preparation of the contractor Electromagnetic Compatibility Program that is included in the contractual agreement.

DISCUSSION

This handbook is not included in the specification tree. It offers needed guidance for forming an EMC plan. However, the only way to implement the guidance is through other customized documents. Some general specification similar to MIL-E-6051 is needed to more simply gain contractual control. There is clear guidance in MIL-HDBK-237 on data needs.

F-9. MIL-STD-1605 (Ships), Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 20 Apr 1973.

F10. MIL-HDBK-237. Electromagnetic Compatibility/Interference Program Requirements, 20 Apr 1973.

MIL-E-6051 ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS, SYSTEMS[F-11]

DESCRIPTION

This specification outlines the overall requirements for systems electromagnetic compatibility, including control of the system electromagnetic environment, lighting protection, static electricity, bonding and grounding. It is applicable to complete systems, including all associated subsystems/equipments.

DISCUSSION

This specification requires and controls system EMC approaches for aircraft systems. It controls equipment EMI through MIL-STD-461 and the power interface through MIL-STD-704. Lightning protection, hazards to ordnance, and other system considerations are controlled by reference to appropriate specifications. Degradation criteria and safety margins are included. Tests and test reports are controlled. A similar system-level specification (not a handbook or guide) for ship systems would greatly improve EMC control, including control on the electric power/electronics/signal-ground interfaces. Testing is not adequate to detect this type of power-supply deficiency. There is no guidance given on the signal-ground interface.

MIL-F-18870 FIRE CONTROL EQUIPMENT, NAVAL SHIPBOARD, GENERAL SPECIFICATION FOR [F-12]

DESCRIPTION

This specification covers the common requirements for the procurement of fire control equipment to be used in Naval shipboard weapon systems. Such equipment may be a complete system or a part of such a system.

DISCUSSION

The new "E" version of the specification greatly improves the specification with respect to control of the Electric Power/Electronics/Signal Common interfaces. The power interface is controlled by invoking MIL-STD-1399 Section 103 in the Section 3 requirements and the Section 4 test requirements. Harmonic currents drawn by the equipment are controlled. However, leakage current from the input power line to ground (ship hull) is not controlled. A checklist for data needed in the ordering package is provided but there are no requirements for data delivery on equipment performance. This specification is the only one giving clear guidance regarding signal ground. Single-point grounding to the equipment enclosure and then to the ship's hull is required. Technical problems that may be associated with this approach have been discussed in Section 2.5 through 2.7. As with MIL-E-16400, a low-voltage test for switching-mode regulator design deficiencies is needed. For a MIL-F-18870 specification tree, see figure F-2.

F-11. MIL-E-6051D, Electromagnetic Compatibility Requirements, Systems, 7 September 1967: Amendment 1 (USAF), 5 July 1968.

F-12. MIL-F-18870E (OS), Fire Control Equipment, Naval Shipboard, General Specification for, 25 Apr 1975.

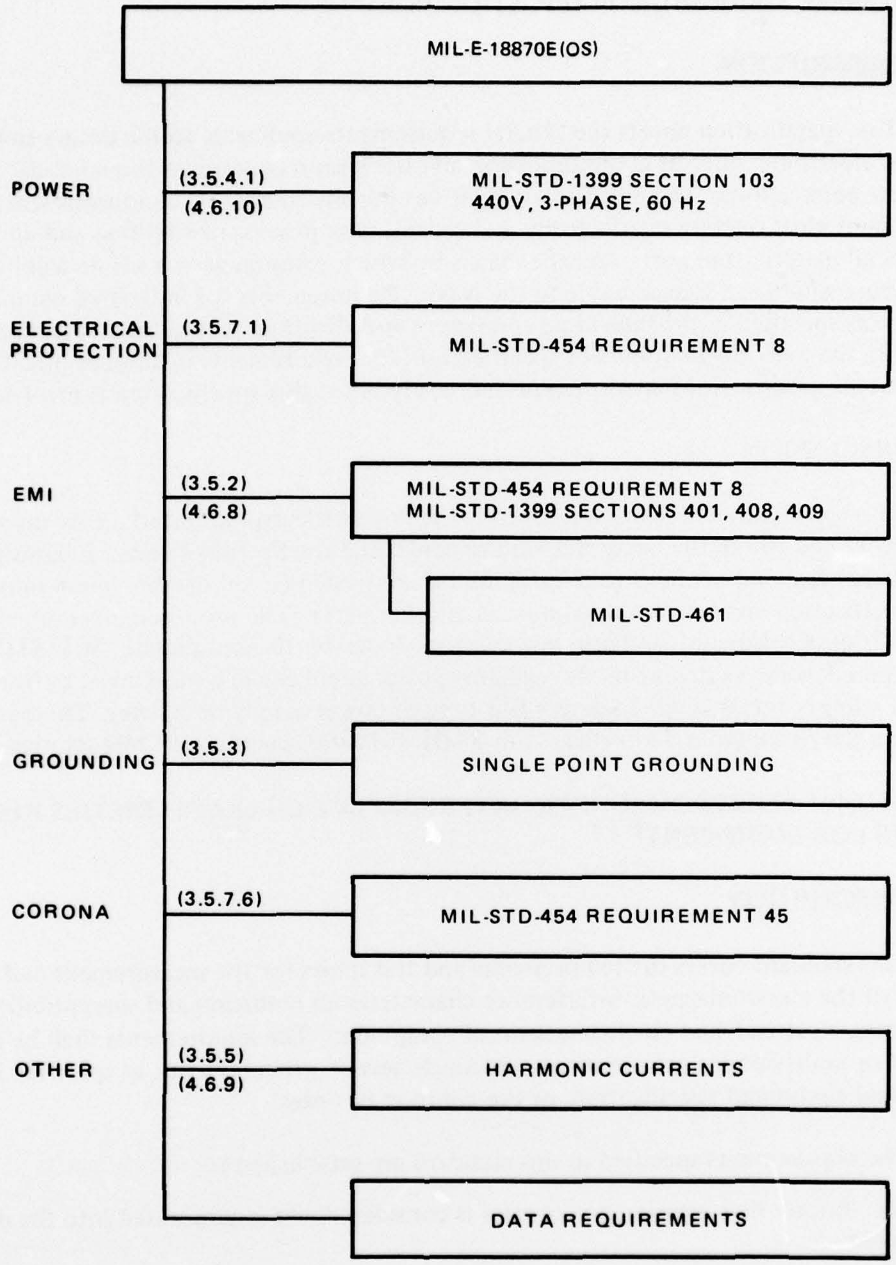

Figure F-2. MIL-F-18870E(OS) EM-power specification tree.

MIL-E-16400, ELECTRONIC, INTERIOR COMMUNICATION AND NAVIGATION EQUIPMENT, GENERAL SPECIFICATION FOR[F-13]

DESCRIPTION

This specification covers the general requirements applicable to the design and construction of electronic, interior communication and navigation equipment intended for Naval ship or shore applications. This specification defines the environmental conditions within which equipment must operate satisfactorily and reliably; the process of selection and application of general material and parts; and the means by which equipment as a whole will be tested to determine whether it is acceptable to the Navy. Requirements for individual equipments shall be as specified in the individual equipment specification. Unless otherwise specifically stated in the individual equipment specification, the requirements of this specification and any and all specifications cited therein shall apply when this specification is invoked.

DISCUSSION

This specification adequately controls the Power/Electronics interface by invoking MIL-STD-1399 Sec 103 in the Section 3 requirements, and the Section 4 tests. In addition, leakage current from power lines to the ship hull is controlled (to 30 ma maximum in one part of the specification and to 5 ma maximum in another part). The proposed amendment -1 to MIL-E-16400G also controls harmonic currents drawn by the equipment. MIL-STD-461 tests are required; some switching-mode regulator power supplies can be destroyed by low input voltages. Testing is not adequate to detect this type of power-supply deficiency. There is no guidance given on the signal-ground interface. For a MIL-E-16400 specification tree see figure F-3.

MIL-STD-461 ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS REQUIREMENTS FOR EQUIPMENT[F-14]

DESCRIPTION

This standard covers the requirements and test limits for the measurement and determination of the electromagnetic interference characteristics (emission and susceptibility) of electronic, electrical, and electromechanical equipment. The requirements shall be applied for general or multi-Service procurements and single service procurements, as specified in the individual equipment specification, or the contract or order.

The requirements specified in this standard are established to:

(a) Ensure that interference control is considered and incorporated into the design of equipment.

(b) Enable compatible operation of the equipment in a complex electromagnetic environment.

F-13. MIL-E-16400G (Navy) Electronic, Interior Communications and Navigation Equipment, Naval Ship and Shore, General Specification For, 24 December 1974.

F-14. MIL-STD-461A, Electromagnetic Interference Characteristics, Requirements for Equipment, 1 August 1968: Notice 1, 7 Feb 1968; Notice 2, 20 Mar 1969; Notice 3, (USAF), 1 May 1970; Notice 4 (EL), 9 Feb 1971; Notice 5, 6 Mar 1973; Notice 6, 3 Jul 1973.

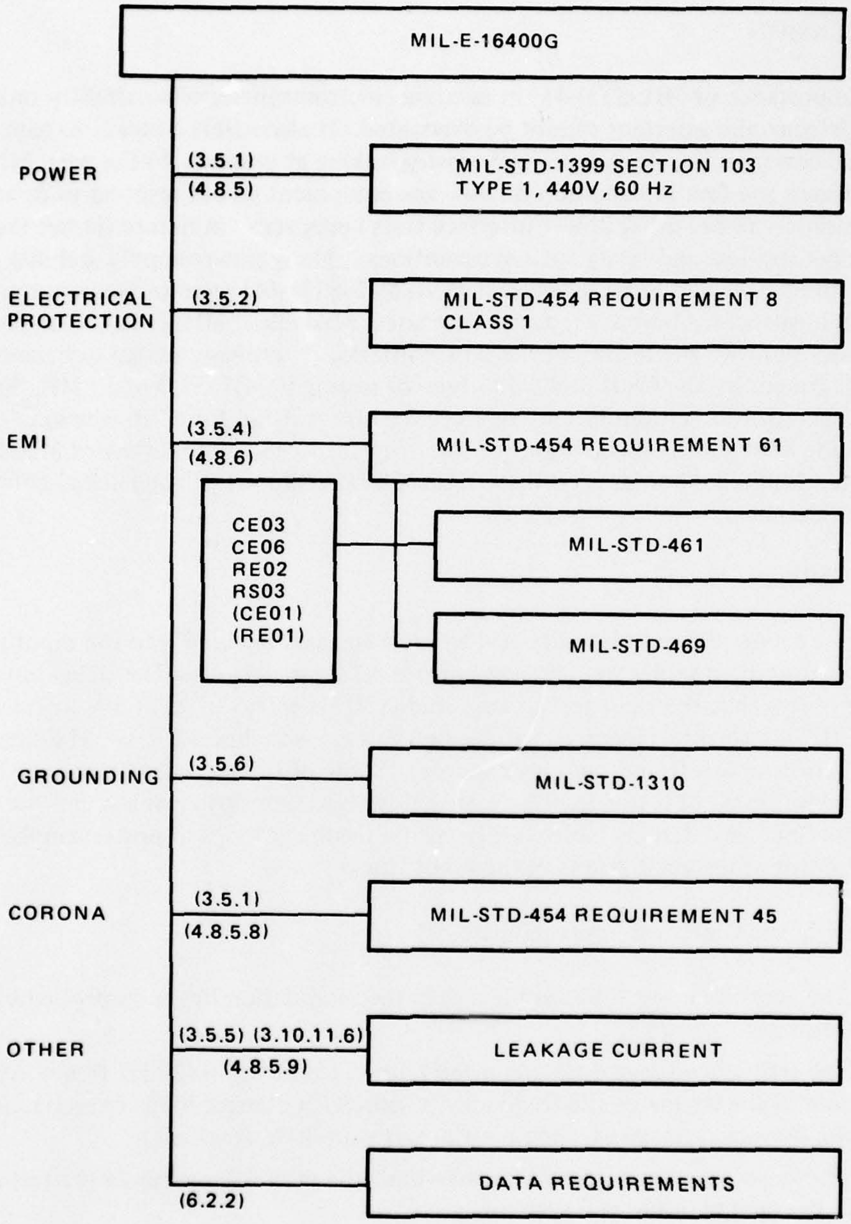

Figure F-3. MIL-E016400G EM-power specification tree.

This standard shall be used in conjunction with MIL-STD-463 and MIL-STD-462.

DISCUSSION

The importance of MIL-STD-461 in assuring electromagnetic compatibility on the electric power/electronics interface cannot be overstated. It also offers a means to gain control of the signal-common interface, a control mostly lacking at present. In the past, MIL-STD-461 test offered the first information on how the equipment would respond to dynamic system conditions – all the other power interface tests being static in nature (ie, set the source voltage 10 percent low and verify system operations). Many power-supply stability loops and many filters have had to be redesigned when MIL-STD-461 type tests uncovered design deficiencies unsuspected before the tests. The latest versions of MIL-E-16400 and MIL-F-18770 greatly improve the testing of the power interface, yet many design deficiencies can still only be caught by the CS01 and CS06 type of testing in MIL-STD-461. MIL-STD-461 is a complex specification currently undergoing extensive revision for a "B" version.[F-15,F-16] In the funding level and time constraint of this project, no adequate review of MIL-STD-461 was possible. Limited comments on three tests (CS01, CS06, CE01) and signal common test possibilities are made.

CS01

This is a conducted susceptibility test where a signal is injected into the input power leads to the equipment under test and swept from 30 Hz to 50 kHz. The signal has a source impedance of less than 0.5 ohm and an amplitude (30 Hz to 1.5 kHz) of 3-V ac rms (6-V ac rms in the "B" version) or 10 percent of the line voltage, whichever is less. The signal simulates modulation signals found on power sources. Some of the modulation may be inherent in the source but most of it is caused by interactions between various loads and the power system. The CS01 test detects faulty design of the feedback loops in power supplies and inadequate control of resonant points in the input filters.

Review of the CS01 test limits indicates:

(a) The amplitude test limits are less than the modulation limits controlled by MIL-STD-1399 sec 103,

(b) The frequency range does not extend down to the 0.8-to-25-Hz frequency range corresponding to the characteristic frequency of generator control loops (which is also the characteristic frequency range of some poor power supply designs), and

(c) The 0.5-ohm source impedance may limit the available energy in the test to a value far less than the energy in the real system.

Most of these limitations are the result of limitations in the test equipment and the methods used for the CS01 tests. Even though the test is limited in amplitude, lower frequency range, and impedance, its value is such that it should not be waived. There is a need to

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F-15. Interference Technology Engineers Master Directory and Design Guide (ITEM 1976), R&B Enterprises, Plymouth Meeting, PA 1976, 128, 129, and foldout. Military EMC Specifications, MIL-STD-461B, A Summary of Tentative Requirements of the "B" Version.

F-16. Correspondence received 5 Sept 1976, from Steve Caine, ELEX 51024, to Jerry Foutz, NELC 4340, Latest Proposed Curves for MIL-STD Limits for CE01, CS01, and CS06

overcome present limitations in the test and realign the limits to be compatible with what electronic equipment can experience when installed aboard ships.

CS06

This is a conducted susceptibility test where spikes are injected into the input power leads to the equipment under test. The injected spikes simulate the spikes seen in power systems. The primary cause of the spikes is the interruption or rapid change in current in inductive circuits. For example, a circuit breaker opening can cause large spikes on the power distribution cables to the equipment. The spike-test limits often determine the voltage rating and circuit configuration of equipment input filters. The spike test can detect conditions such as (a) parasitic coupling paths from input to load; (b) poor EMI filter configuration which delivers spikes to the load, bypassing power supplies and other filters; and (c) poor impulse response of filters and control loops. Limits used and proposed for MIL-STD-461B range from 100 V to 400 V. Spikes seen in ships have been high enough to result in a 2500-V spike requirement in MIL-STD-1399 sec 103.

CE01

This conducted emission test measures ac current between 30 Hz and 20 kHz flowing in the power lines when there is a low ac impedance to ground (ship hull). This frequency range is within the range of the harmonic currents related to the fundamental power line frequency.

In the proposed MIL-STD-461B, the specification limits have been changed to be compatible with the 3-percent harmonic current limit (of MIL-E-16400F Amendment 1, and MIL-F-18870E) for 60-Hz, 440-V, 3-phase loads greater than 1 kVA and for 400-Hz, 400-V, 3-phase loads greater than 0.2 kVA. The limits are more relaxed for lower power loads and tighter for single-phase loads and for 115-V input power. One of the purposes for invoking these limits is to prevent electronic equipment from causing harmonic voltage distortion limits being exceeded on the MIL-STD-1399 Sec 103 interface. The limits proposed are expected to accomplish this. Other purposes for the CE01 test were not investigated.

SIGNAL COMMON

Rejection of common mode noise on signal lines/signal common between electronic equipments, and the effect of circulating signal-common currents on signals, are presently poorly controlled. MIL-STD-461 could be expanded to control and test for these effects.